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Integration of Air Traffic Databases - A Case Study

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13. ABSTRACT (Maximum 200 words)

This report describes a case study to show the benefits from maximum utilization of existing air traffic databases. The study demonstrates the utility of integrating available data through developing and demonstrating a methodology addressing the issue of airport performance.

The study utilized data bases which addressed the factors of airport capacity and aircraft delay, and focused on the single airport of Philadelphia International. Since avoidable delays impose major costs to the nation's airlines, the study objective was to better understand the conditions under which delays occur and their causal factors. This will provide guidance for decisions on airport investments which are justified with well-defined benefits.

The report presents quantitative measures of average delay, number of delayed flights, and total delay. As expected, there were more delayed flights and longer average delays under poor weather conditions than under better weather conditions. However, total delay under good weather conditions considerably outweighs the total delay experienced under poor weather conditions. The report also demonstrates a quantitative relationship between average delay and the demand/capacity ratio at the airport. This should prove to be especially useful in the investment analyses of airport improvements.

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PREFACE

This work was conducted by the Volpe National Transportation Systems Center (Volpe Center) for the Federal Aviation Administration's Operations Research Service (AOR). In April 1994, AOR requested the Volpe Center to conduct a study which would show how existing data at the agency could be used in an integrated manner to address issues of importance to FAA investment priorities and air traffic concerns. This report is the result of that effort. Charles T. Phillips of the Surveillance and Sensors Division was project leader for the Volpe Center.

The information used in this report was preliminary, and the results reported here do not necessarily reflect any conclusion or policy taken by the U. S. Department of Transportation, the Federal Aviation Administration, or AOR.

The author wishes to acknowledge the assistance of Eugene Gilbo and Tom Narayan of the Unisys Corporation, who developed many of the data analyses important to the conduct and conclusions of the study. He also wishes to acknowledge Dan Citrenbaum and Art Politano of AOR for their guidance and coordination in pursuing this fruitful area of analysis.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

$[(x-32)(5/9)]$ °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (k)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (he) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)	=	1.1 short tons

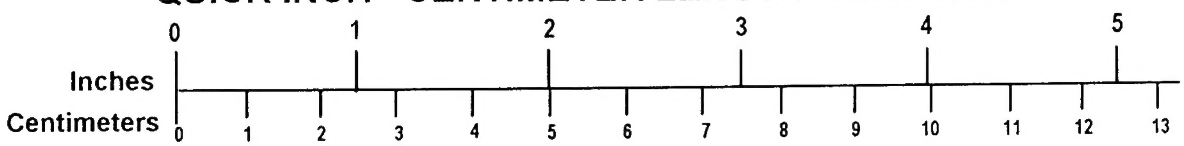
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

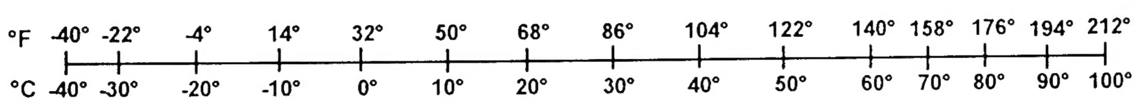
TEMPERATURE (EXACT)

$[(9/5)\ y + 32]$ °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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EXECUTIVE SUMMARY

The Volpe National Transportation Systems Center (Volpe Center) conducted a pilot project as a case study to show the benefits from increased utilization of existing air traffic databases. The utility of integrating available data was demonstrated, and a methodology was developed and demonstrated addressing the issue of airport performance.

The study utilized databases which addressed the factors of airport capacity and aircraft delay. The study also focused on a single airport, namely, Philadelphia International. Since avoidable delays, e.g., delays caused by weather or traffic congestion, impose major costs to the nation's airlines, it is important to better understand the conditions under which delays occur and their causal factors. This will provide guidance for decisions on airport investments which are justified with well-defined benefits.

Two separate analyses were performed in the study. The first used the FAA's Consolidated Operations and Delay Analysis System (CODAS) data set. In this analysis, airline delays at Philadelphia were correlated with weather conditions occurring at the time of landing or takeoff. The second analysis combined, for the first time, individual flight information from a major airline with data available from the Enhanced Traffic Management System (ETMS). This combination matched airline flights by flight time with ETMS data relating to the same time. In this analysis, airline delays at Philadelphia were related to airport utilization as well as weather conditions.

The results gave quantitative measures of average delay, number of delayed flights, and total delay. As expected, there were more delayed flights and longer average delays under poor weather conditions than under better weather conditions. However, total delay under good weather conditions considerably outweighs the total delay experienced under poor weather conditions.

The most interesting result, obtained from the combination of airline and ETMS data, was the determination of a quantitative relationship between average delay and the demand/capacity ratio at the airport. This should prove to be especially useful in the investment analyses of airport improvements. If the FAA is successful in negotiating the large scale use of flight-specific data from the major airlines, extensions of the methodology shown here should help create accurate metrics to aid in investment decisions.

1. INTRODUCTION

1.1 BACKGROUND/OBJECTIVE

The FAA and the Department of Transportation have collected a significant amount of data concerning diverse aspects of aviation, and maintain a number of current databases. The FAA's Operations Research Service (AOR) asked the Volpe National Transportation Systems Center (Volpe Center) to conduct a pilot project, serving as a case study, showing the payoff from properly utilizing this wealth of data. In particular, the study would:

- Demonstrate the utility of integrating available data

- Develop and demonstrate a methodology which enlists available data to illuminate a practical agency problem.

We decided to address the issue of airport performance at a single airport to limit the scope of the study. We chose Philadelphia International Airport (PHL) because it:

- Is one of the top 20 airports in total delay

- Is a major hub

- Has significant periods of bad weather.

1.2 THE AIRPORT PERFORMANCE ISSUE

Airport performance is an important and not easily defined concept. Qualitatively, increasing airport performance will increase the value of an airport as a resource within the National Airspace System. The following is a representative but by no means exhaustive list of factors related to airport performance:

- Safety under a variety of weather conditions

- Continuity of operations under a variety of weather conditions

- Controller workload and productivity

- Airspace capacity

- Airport capacity

- Aircraft delays

In this case study, we will deal with only the last two factors.

1.2.1 Airport Capacity

Airport capacity, or more simply capacity in this report, is again not easily defined. In the FAA Strategic Plan,[1] under System Capacity, Objective 5A is "System Capacity Measurement - Identify and define, in concert with the aviation community, standards of success and national capacity indicators which will better target areas for reducing delays and increasing capacity." A joint Government-Industry task force is now working to better define capacity.[2]

Regardless of how airport capacity is measured, it is an important component of airport performance, since it is an upper limit of throughput, or total operations per hour. Increasing capacity will increase the number of aviation users who will be able to travel at the time that they wish to do so.

This is especially true under conditions of bad weather. Without special landing aids, safe airport operation requires restricted runway configurations and/or miles-in-trail restrictions. Airport surveillance and landing aids such as Airport Surface Detection Equipment (ASDE), weather sensors, and precision runway monitors can greatly increase airport capacity allowed by air traffic control.

1.2.2 Aircraft Delays

Delays at an airport have different causes, e.g.:

- Airline-initiated gate holds
- Estimated Departure Clearance Time (EDCT) gate holds from traffic management
- Departure and landing delays due to high traffic demand relative to capacity

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[1] Federal Aviation Administration, FAA Strategic Plan, Vol. 2: Strategic Implementation, 1994.

[2] FAA National Capacity Indicators Forum, held at the Department of Transportation, September 1, 1994.

This last form of delay will be the focus of this case study; these are avoidable delays in an airport context. These delays occur when demand for departures and arrivals is sufficiently high, that throughput (which is limited by capacity) cannot handle the demand without queuing.

There is a significant economic benefit to reducing avoidable airport delays. For example, in 1991 there were 23 airports which had in excess of 20,000 air carrier annual delay hours.[3] At an estimated cost of $1600/hour,[4] air carriers experienced more than a $32 million annual cost beyond the no-delay situation.

The efficiency benefits of reduced airline delays will be one justification for investment decisions to increase capacity. However, the investment cannot be simplistic; if reducing delays at an airport is the primary reason for the investment, the particular improvements need to be tailored to the type of delay experienced. This requires specific knowledge of the conditions under which delays occur, and the causal factors of the delays.

This case study, therefore, focuses on one aspect of airport performance, namely the conditions under which delays occur and their causal factors. A better understanding of these areas will lead to improved definition of alternative investments, improved cost/benefit analysis of the alternatives, and investment decisions which are justified with well-defined benefits.

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[3] FAA, 1993 Aviation System Capacity Plan 1-21.

[4] FAA, 1993 Aviation System Capacity Plan 1-17.

2. SURVEY OF RELEVANT DATABASES

Table 1 provides a listing of airport-related databases. The two principal sources for the table were: the FAA's Office of Information Technology (AIT) inventory of FAA databases; and DOT's Directory of Transportation Data Sources.[5] From these databases the following were potentially promising sources for the study:

- Air Traffic Operating Management System (ATOMS)
- Airline Service Quality Performance (ASQP)
- Consolidated Operations and Delay Analysis System (CODAS)
- Enhanced Traffic Management System (ETMS)

2.1 ATOMS

ATOMS provides a regular count of air traffic operations, and operations delayed by 15 minutes or more. An advantage is that operations counts per unit time are provided for all aircraft, not just for air carriers. Also, reasons for delay are explicitly identified. However, unlike other databases, it does not provide individual flight characteristics such as flight number and airline. In addition, it is better for analytical purposes to know the length of each flight delay, not simply how many were delayed by 15 minutes or more.

2.2 ASQP

ASQP was developed to support a current report on airlines' on-time performance put out by the Department of Transportation. For most domestic passenger airlines,[6] it shows gate-departure delays and gate-arrival delays for each flight. It lacks the more detailed time and delay records of other databases.

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[5] U.S. Department of Transportation, Bureau of Transportation Statistics, Directory of Transportation Data Sources, 1993.

[6] Domestic passenger airlines with one percent or more of the total domestic scheduled service passenger revenues must report all or nearly all of their flights.

TABLE 1. SELECTED AVIATION DATA BASES AND REPORTS

Information Area	Agency	Data Base Name	Printed Reports
Airports			
	FAA/APP-400	National Plan of Integrated Airport Systems (NPIAS) and Capital Improvement Program	NPIAS 1990-1999: Report of the Secretary of Transportation to the U.S. Congress
	FAA/ARP-10	Airport Improvement Program	
	FAA/ARP-10	Regional Grants Management System	
	FAA/ASC-1		Aviation System Capacity Plan
	FAA/ATM-600	Airport Facilities and AF Facilities	
	FAA/ATM-600	Landing Facilities	
Air Traffic Control (ATC) and Airspace			
	FAA/AFS	Terminal Instrument Procedures	
	FAA/ATM	Obstruction Evaluation and Airport Airspace Analysis	
	FAA/ATM-600	Airspace Fixes	
	FAA/ATM-600	ARTCC Boundaries	
	FAA/ATM-600	Holding Pattern Description	
	FAA/ATM-600	Instrument Landing Database	
	FAA/ATM-600	Navigational Aids	
	FAA/ATM-612	Aeronautical Information System	Airport Facility Directory IFR and VFR Aeronautical Charts
	FAA/ATP	Airspace Rules Processing and Reporting System	
	FAA/AVN	Obstacles	
	NOAA	Standard Instrument Approach Procedures	
Aviation Activity			
	FAA/APO	Air Traffic Delay	
	FAA/APO	Enplanements	
	FAA/APO-110	Forecast	FAA Aviation Forecasts FAA Long-Range Aviation Projections Forecast of IFR Aircraft Handled by ARTCCs
	FAA/APO-110	General Aviation Activity and Avionics Survey System	General Aviation Activity and Avionics Survey
	FAA/APO-110	Terminal Area Forecast	Terminal Area Forecast
	FAA/APO-110		FAA Air Traffic Activity

TABLE 1. SELECTED AVIATION DATA BASES AND REPORTS (cont.)

Information Area	Agency	Data Base Name	Printed Reports
	FAA/APO-130	Aviation Data and Analysis System	
	FAA/ASV/AVN	Air Traffic Activity Data Base	
	FAA/ATM-200	Enhanced Traffic Management System (ETMS)	
	FAA/ATM-300	Air Traffic Operating Management System (ATOMS)	Air Traffic Activity and Delay Report
Air Carrier			
	FAA/APO-110	Air Carrier Activity Information System	Airport Activity Statistics of Certificated Route Carriers
	FAA/APO-130	Consolidated Operations and Delay Analysis System (CODAS)	
	OST/I-23	Airline Service Quality Performance (ASQP)	Air Carrier Consumer Report
	RSPA/DAI-20	Form 41 Financial Schedule	Air Carrier Financial Statistics (Quarterly)
	RSPA/DAI-20	Form 41 Schedule T-1 Form 298-C	Air Carrier Industry Scheduled Service Traffic Statistics (Quarterly)
	RSPA/DAI-20	Form 41 Schedule T-3	Air Carrier Traffic Statistics (Monthly)
	RSPA/DAI-20	Schedule P-12(a) Fuel Consumption by Type of Service and Entity	

2.3 ETMS

A database of flights as recorded by ETMS is available at the Volpe Center, where the automation system supporting flow control resides. This database contains flights for which flight plans were filed and includes flight departure and arrival messages. Departure and arrival demand is available for each period of time using the flight plans. Another database has records of weather conditions at airports at any time.

2.4 CODAS

This database integrates, for most domestic scheduled flights, records from several sources including ASQP, ETMS, and weather. It has developed simple estimates of delay by phase of flight using the ETMS departure (DZ) and arrival (AZ) messages.

2.5 Airline

An additional source of data became available for the study. A major airline supplied all flights departing from or arriving at PHL over a period of time, with the airline's recorded times for:

- Out of the gate
- Off the (departure) runway
- On the (arrival) runway
- Into the gate,

informally known as OOOI data. Each flight had scheduled departure and arrival times, so that departure and arrival delays were calculated. In addition, each flight had an expected taxi time, so actual taxi delays were recorded. The OOOI data is expected to become available on a large scale following an agreement between the airlines and the FAA to provide a data link from the ARINC Communications Addressing and Reporting System (ACARS).

The decision was made to use the CODAS, ETMS, and airline data since they best fit the needs for this case study.

3. METHODOLOGY AND DATA DESCRIPTION

The following data in this section were used to develop:

- A statistical analysis of delays as related to weather conditions, using the CODAS data

- A statistical analysis of delays as related to both weather conditions and airport utilization, using combined ETMS and airline data.

3.1 CODAS DATA DESCRIPTION AND USE

Figure 1 shows a schematic of the CODAS data utilized. National files of all CODAS flights were obtained[7] for the months of October, November, and December 1992. From these were extracted files consisting of Philadelphia departures only, and Philadelphia arrivals only. Taxi delays were correlated with weather conditions, and the data elements shown in the figure were used.

Four basic weather conditions at an airport have been defined as shown in Figure 2, based on ceiling and visibility. These are:

- Visual Flight Rules (VFR) allowed

- Marginal VFR (MVFR)

- Instrument Flight Rules (IFR) required

- Low IFR (LIFR)

For the purposes of this study, the CODAS data were analyzed in three groups:

- All weather

- All IFR: visibility $\leq$ 3 miles, or ceiling $\leq$ 1000 feet

- Low IFR (LIFR): visibility $\leq$ 1 mile, or ceiling $\leq$ 500 feet

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[7] Obtained courtesy of APO-130 by way of the Volpe Center's Economic Analysis Division, which was using the data in support of the FAA's Vertical Flight Program Office (ARD-30).

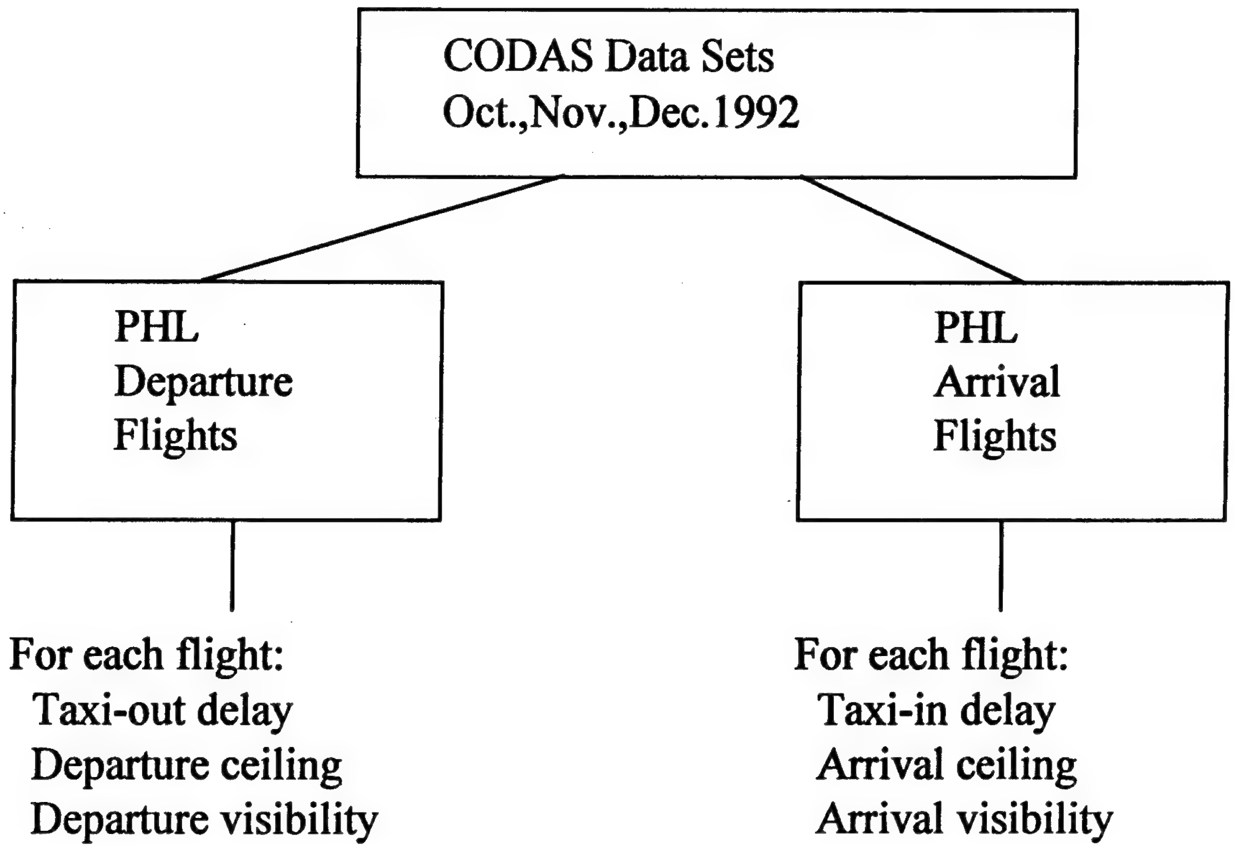


FIGURE 1. SCHEMATIC OF CODAS DATA UTILIZED

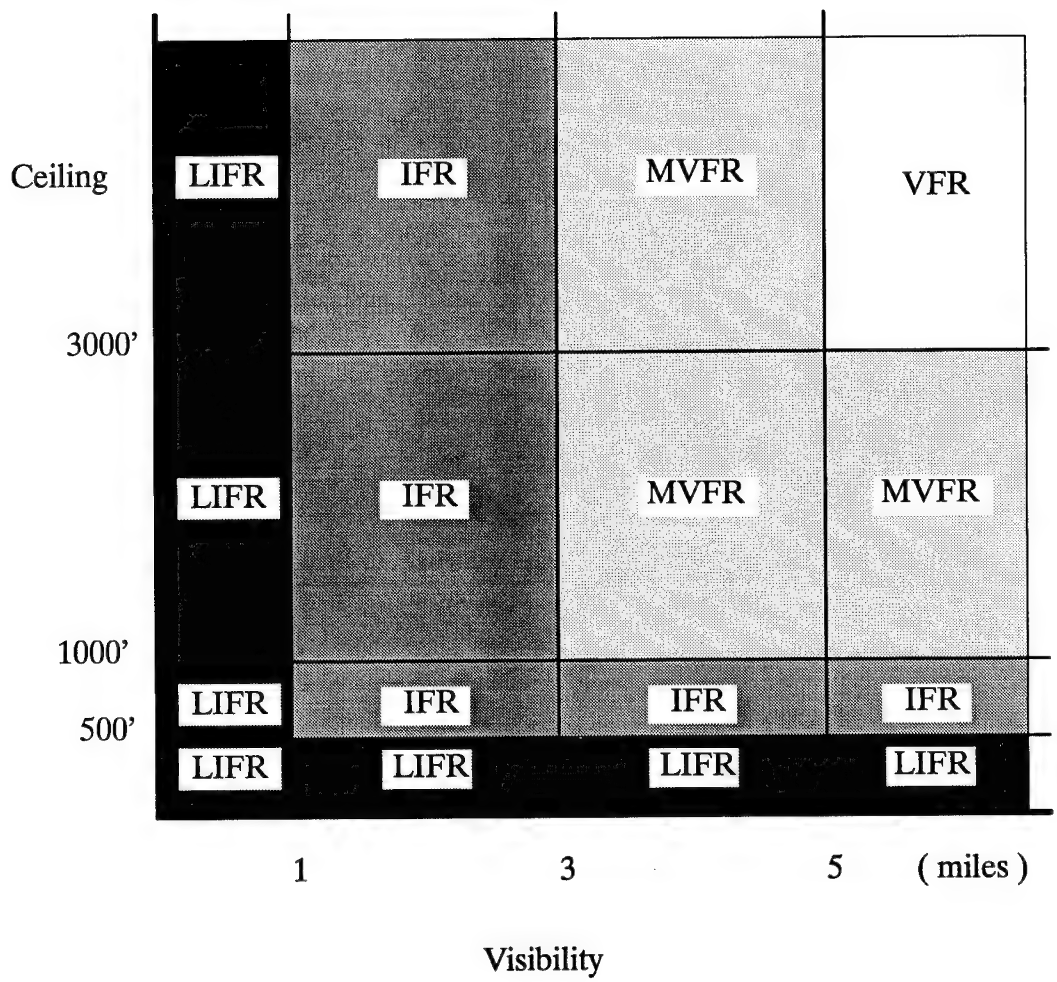


FIGURE 2. OPERATION CATEGORY AS A FUNCTION OF VISIBILITY AND CEILING

The category "all VFR" was then the difference between all weather and all IFR, after eliminating cases where weather information was missing. Statistics showed that it was not meaningful to separate VFR and marginal VFR (MVFR).

The CODAS data for the months of October, November, and December 1992 were then analyzed and combined over the three months to show mean, standard deviation, distributions, and total delay for: 1) taxi-out delays on flights departing PHL, and 2) taxi-in delays on flights arriving at PHL.

3.2 ETMS/AIRLINE DATA DESCRIPTION AND USE

Figure 3 shows a schematic of the ETMS/airline data utilized. Although the airline supplied a file covering all PHL departures and arrivals for calendar year 1993, the ETMS data available at the Volpe Center was incomplete for that year. Therefore, the analysis was conducted for the months September through December 1993 only.

From the ETMS data, a database consisting of PHL departure and arrival flights was extracted. A second database supplied weather information at PHL. The third information source was a set of departure/arrival capacity curves, calculated according to the method previously described by Gilbo.[8]

From the airline data, separate files were created for departure flights and for arrival flights. As described below, actual airline departure delays were correlated with airport utilization and weather. A similar analysis was done using actual airline arrival delays.

3.2.1 ETMS Data Use

The following steps were followed using ETMS data only:

1. Determine arrival-departure demand profiles (time sequences) from filed flight plans, as amended up to 1 hour before departure or arrival. The reason for the 1-hour rule is to estimate intrinsic demand at the airport, before traffic managers start to smooth things out. The demand is determined for each 15-minute interval. This is the definition of "demand" in the subsequent discussion.

2. Determine weather conditions for each 15-minute interval. This is done by applying periodic airport weather surface observations available within ETMS to these time intervals. The same definition of conditions is used as in Figure 2, however only two levels are used - "all VFR" which is called VFR, and "all IFR" which is called IFR.

[8] Eugene Gilbo, "Airport Capacity: Representation, Estimation, Optimization", IEEE Transactions on Control Systems Technology, Vol. 1, No. 3, pp. 144-154, 1993.

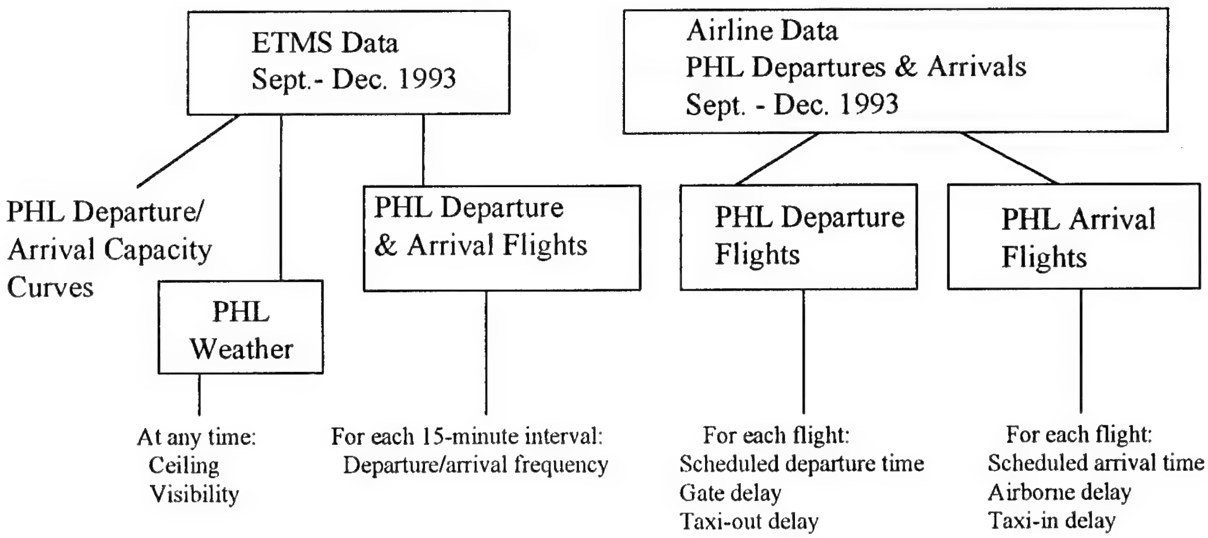


FIGURE 3. SCHEMATIC OF ETMS/AIRLINE DATA UTILIZED

3. Determine arrival-departure airport capacity curves for PHL over the four-month period of data analysis. The techniques used to develop these are described in Gilbo[8]. Briefly, an analysis of a long time-series of departure/arrival pairs in each 15-minute interval shows that controllers cannot push through more aircraft than shown in the curves except for occasional outliers. The results are shown in Figure 4 for VFR and IFR conditions, respectively.

Since airport/runway configuration used at PHL as a function of time, was not available, the curves shown in Figure 4 are averaged over the different configurations.

4. Determine optimal numbers of arrivals and departures which would result if the Tracon/Tower managers were to assign arrivals and departures, given the profile determined from step 1 above, to each 15-minute interval that would minimize total delay. This methodology is also described in Gilbo.[8] The numbers of departures and arrivals so determined in each 15-minute interval are what is referred to as "capacity" in the subsequent discussion.

These metrics are a measure of airport maximum performance at any given time, given the constraints of weather and irregular demand. The arrival-departure pairs will lie on the curves of Figure 4 for VFR and IFR weather conditions, respectively.

3.2.2 Combined ETMS/Airline Data Use

The following steps were followed using combined ETMS and airline data:

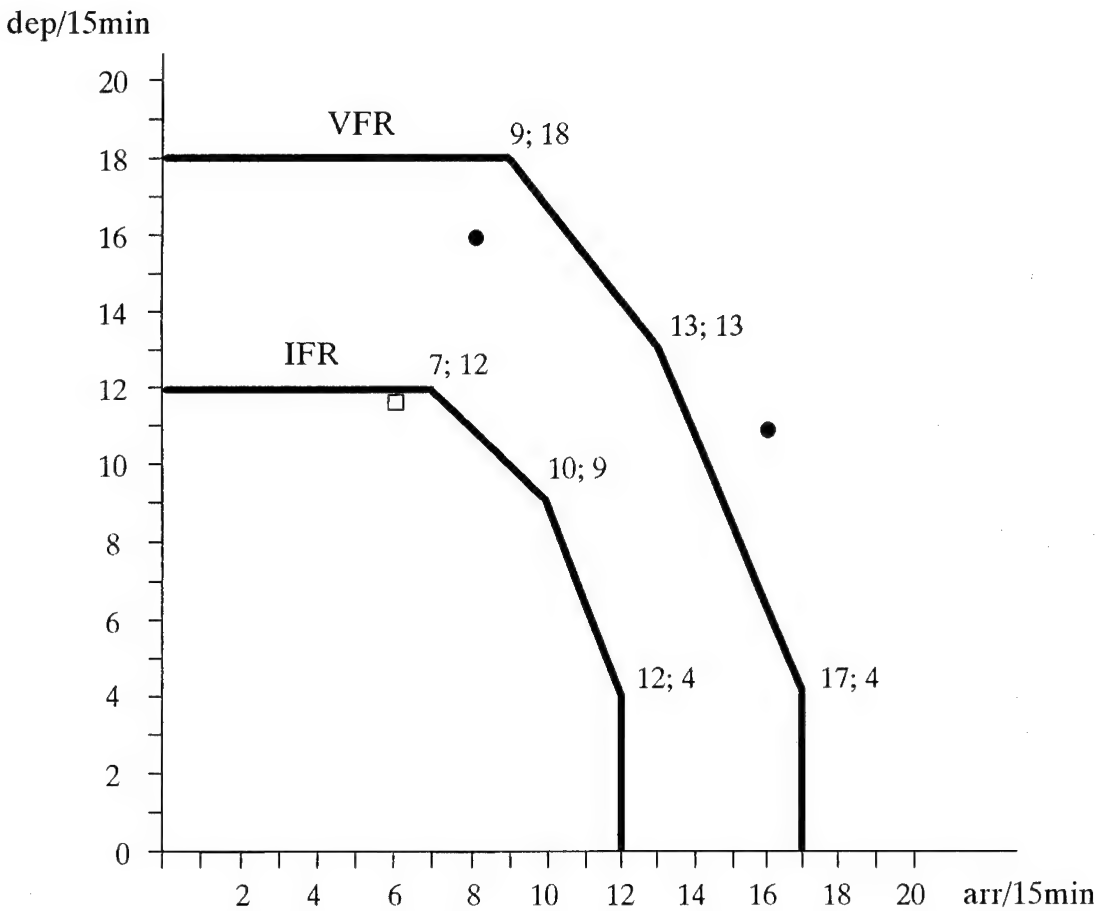
1. Determine the demand to capacity ratios (departures and arrivals) in each 15-minute interval that an airline flight was scheduled to arrive or depart. Show the statistical distributions of these metrics and the effects of weather.

2. Perform statistical analyses of airline flight delays in relation to the airport demand-to-capacity metrics defined in step 1 above and weather conditions, at the time the flight was scheduled.

If air traffic managers behaved in the optimal way specified in Gilbo,[8] there would be no delays when the demand-to-capacity metric is <1. When this metric exceeds 1, there would be queues and delays despite the best efforts of air traffic. In practice, delays occur from other causes than considered here. Also imperfect conditions should cause a steady increase in delay as the demand-to-capacity metric increases.

3.3 DELAY MEASURES IN CODAS AS COMPARED WITH AIRLINE DATA

Taxi-out and taxi-in delays are used in the analysis of both data sets. However, the sources of these data are quite different. One may conclude that the delays calculated for the same flights are likely to differ for the two data sets.



● and □ show EPS (Engineered Performance Standards) for VFR and IFR, respectively.

FIGURE 4. VFR AND IFR PERFORMANCE CURVES FOR PHL (AIRPORT CAPACITY CURVES)

The airline data records allowed use of the following:

taxi-out time = off-runway time - actual gate departure time

taxi-out delay = taxi-out time - standard taxi-out time

where the standard taxi-out time varies by flight. This calculation allows negative taxi delays.

Similarly,

taxi-in time = actual gate arrival time - on-runway time

taxi-in delay = taxi-in time - standard taxi-in time

where the standard taxi-in time varies by flight.

CODAS data records did not have actual off-runway and on-runway times. These were approximated using the DZ (departure) and AZ (arrival) message times which are captured by ETMS. Actual gate departure and arrival times are obtained in CODAS from the ASQP database. The resulting formulas are the following:

taxi-out time = DZ time - actual gate departure time - average DZ gap,

where average DZ gap is the average time from Wheels-Off to DZ message time as a function of departure airport and carrier.

taxi-out delay = taxi-out time - standard taxi-out time if >0; else 0

where standard taxi-out time is an empirically determined number which varies by carrier but not by flight. This calculation does not allow negative delays.

Similarly,

taxi-in time = actual gate arrival time - AZ time - average AZ gap

where average AZ gap is the average time from AZ time to Wheels-On as a function of arrival airport and carrier.

taxi-in delay = taxi-in time - standard taxi-in time if >0; else 0

where the standard taxi-in time is an empirically determined number which varies by carrier but not by flight.

4. RESULTS

4.1 DELAYS BY WEATHER CONDITION USING CODAS DATA

4.1.1 Taxi-Out Delays

Figures 5, 6, and 7 show histograms of taxi-out delay for departing flights at Philadelphia for all weather conditions, IFR weather conditions (including low IFR), and low IFR only. The delay distribution for IFR is not very different from that for all weather, while the distribution for low IFR shows significantly more delayed flights with a higher magnitude of delay as compared to all flights.

Figure 8 shows the distribution of taxi-out delay by different weather conditions after removing the effect of missing data. This shows that the majority of aggregate delay occurs under VFR conditions. Table 2 below shows that mean delays increase under worse weather conditions.

TABLE 2. TAXI-OUT DELAY STATISTICS

Weather	No. of Cases	Mean Delay (mins.)	Std. Dev. of Delay (mins.)	Aggregate Delay (mins.)
All Weather	17575	2.8	5.3	48444
All IFR	1630	3.8	6.3	6210
Low IFR	824	4.6	6.9	3755

4.1.2 Taxi-In Delays

Figures 9, 10, and 11 show histograms of taxi-in delay for arriving flights at Philadelphia. In this case, the distributions for IFR and low IFR both show noticeable differences from the all-weather distribution.

Figure 12 shows the distribution of taxi-in delay after removing the effect of missing data, and Table 3 shows taxi-in delay statistics. The same conclusions apply as stated previously for taxi-out delays.

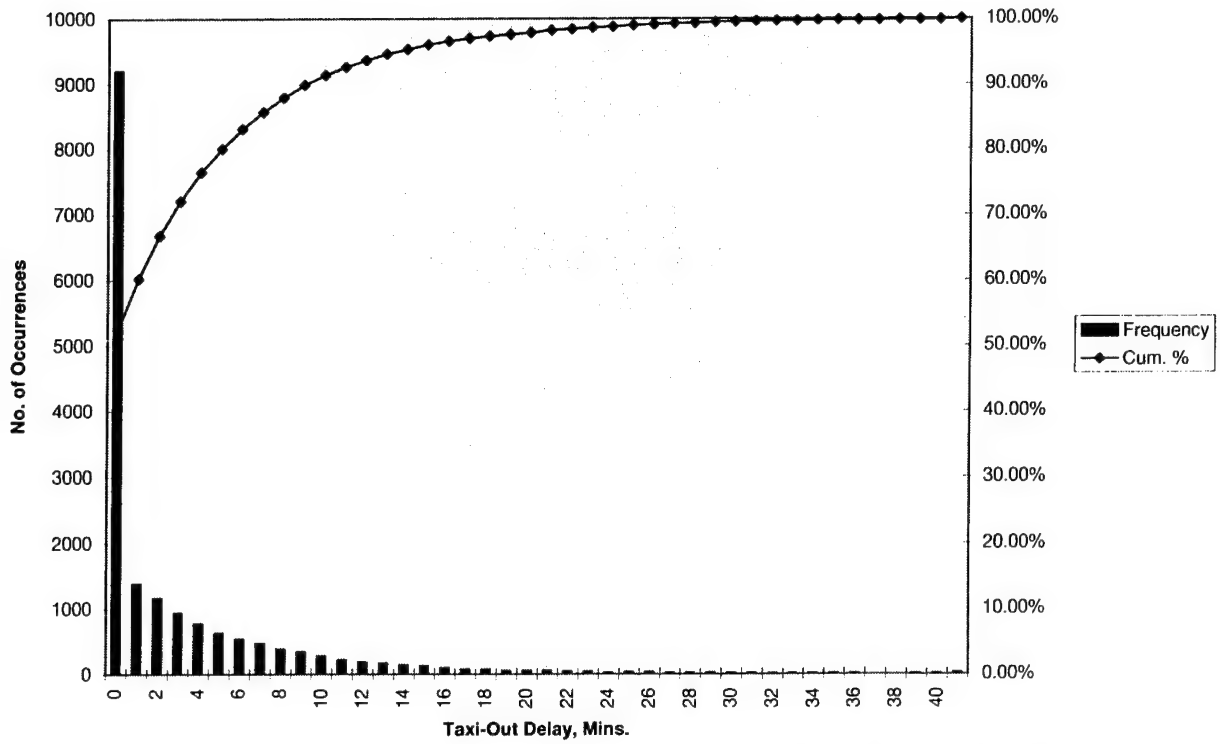


FIGURE 5. TAXI-OUT DELAY, ALL WEATHER CONDITIONS

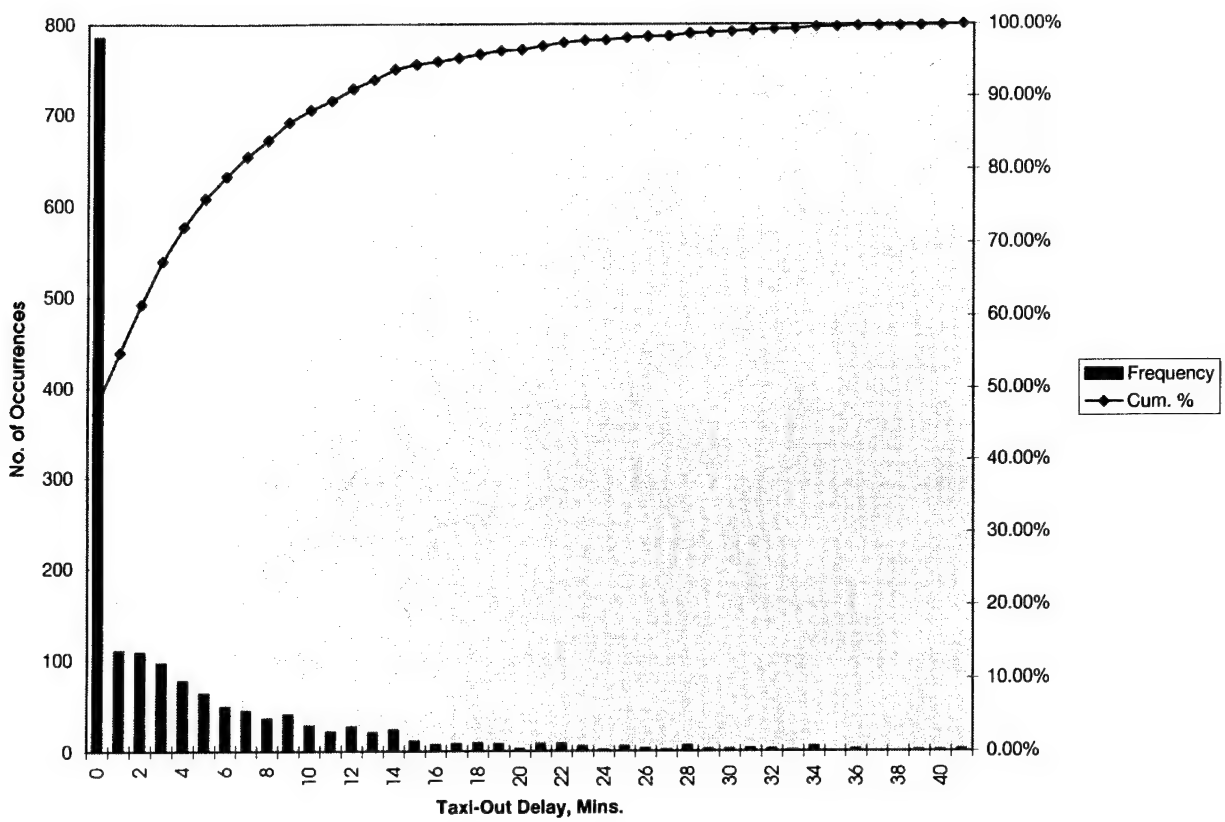


FIGURE 6. TAXI-OUT DELAY, IFR WEATHER CONDITIONS

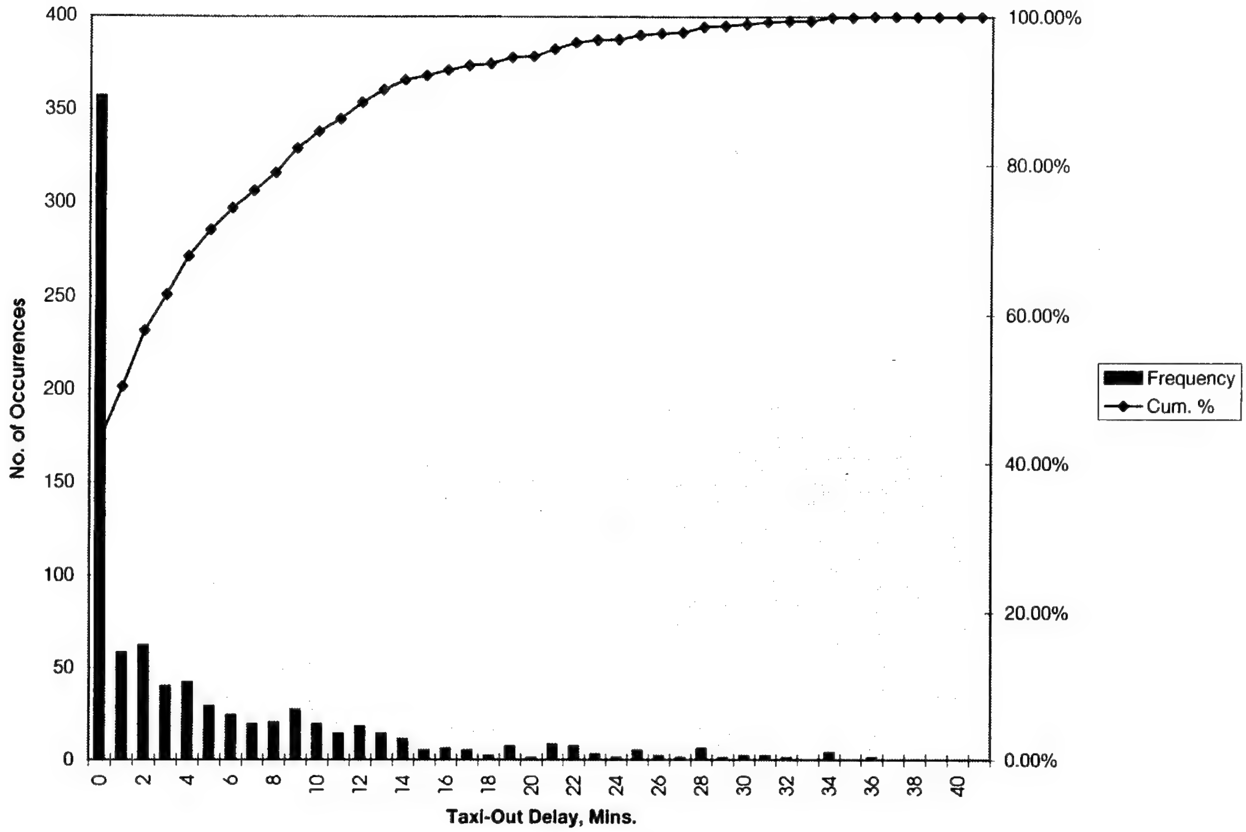


FIGURE 7. TAXI-OUT DELAY, LOW IFR WEATHER CONDITIONS

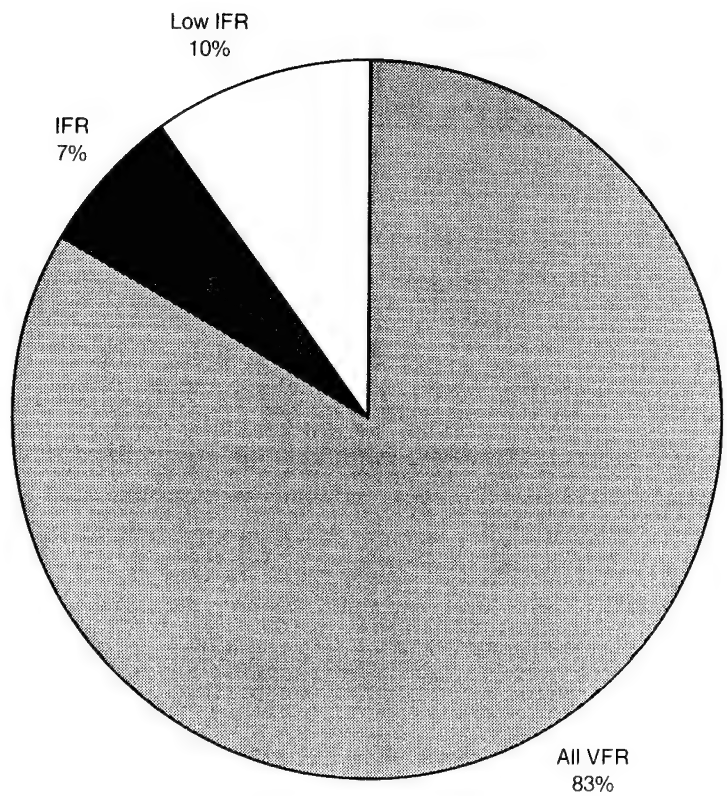


FIGURE 8. TOTAL TAXI-OUT DELAY BY WEATHER CONDITION

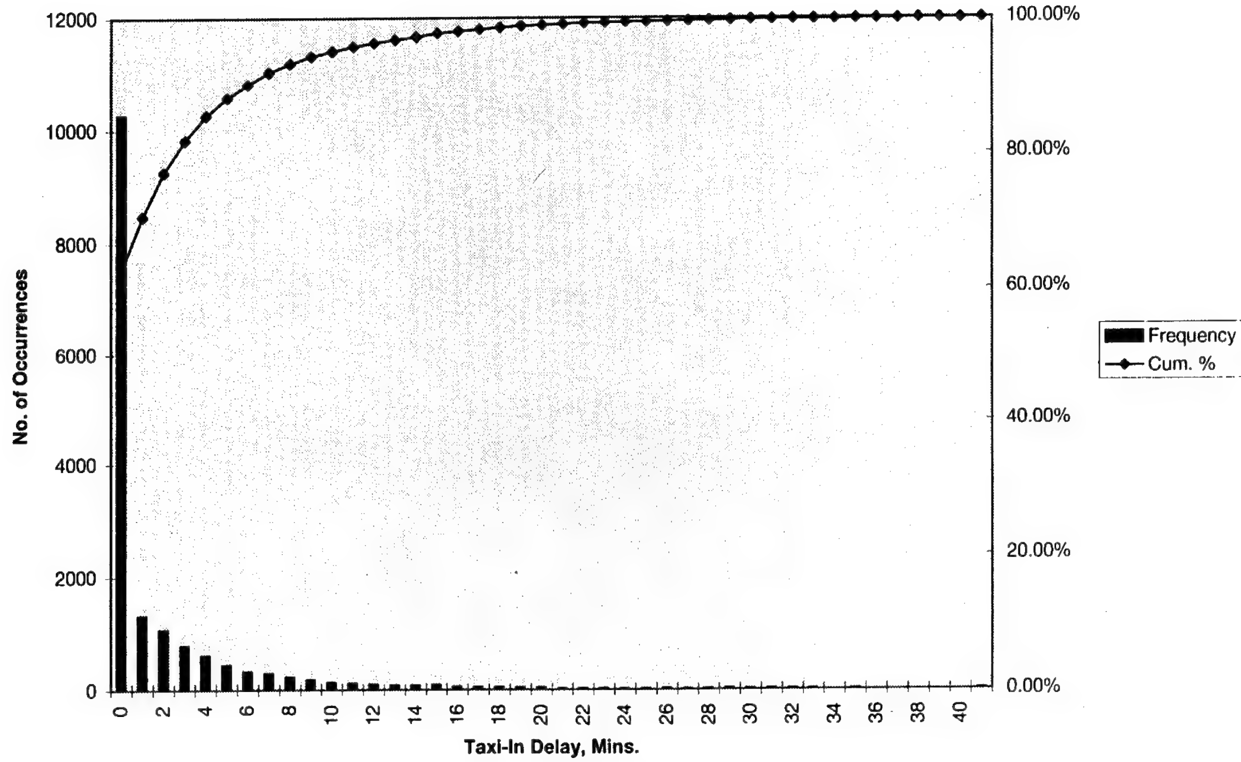


FIGURE 9. TAXI-IN DELAY, ALL WEATHER CONDITIONS

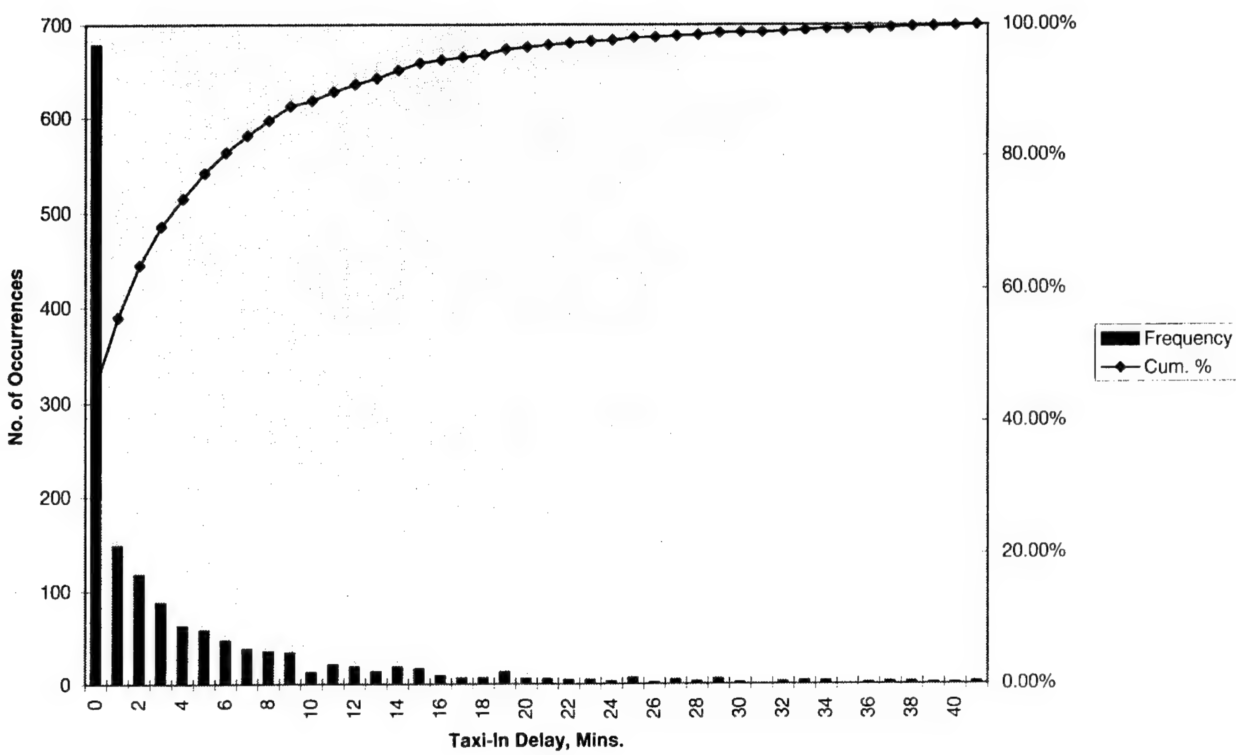


FIGURE 10. TAXI-IN DELAY, IFR WEATHER CONDITIONS

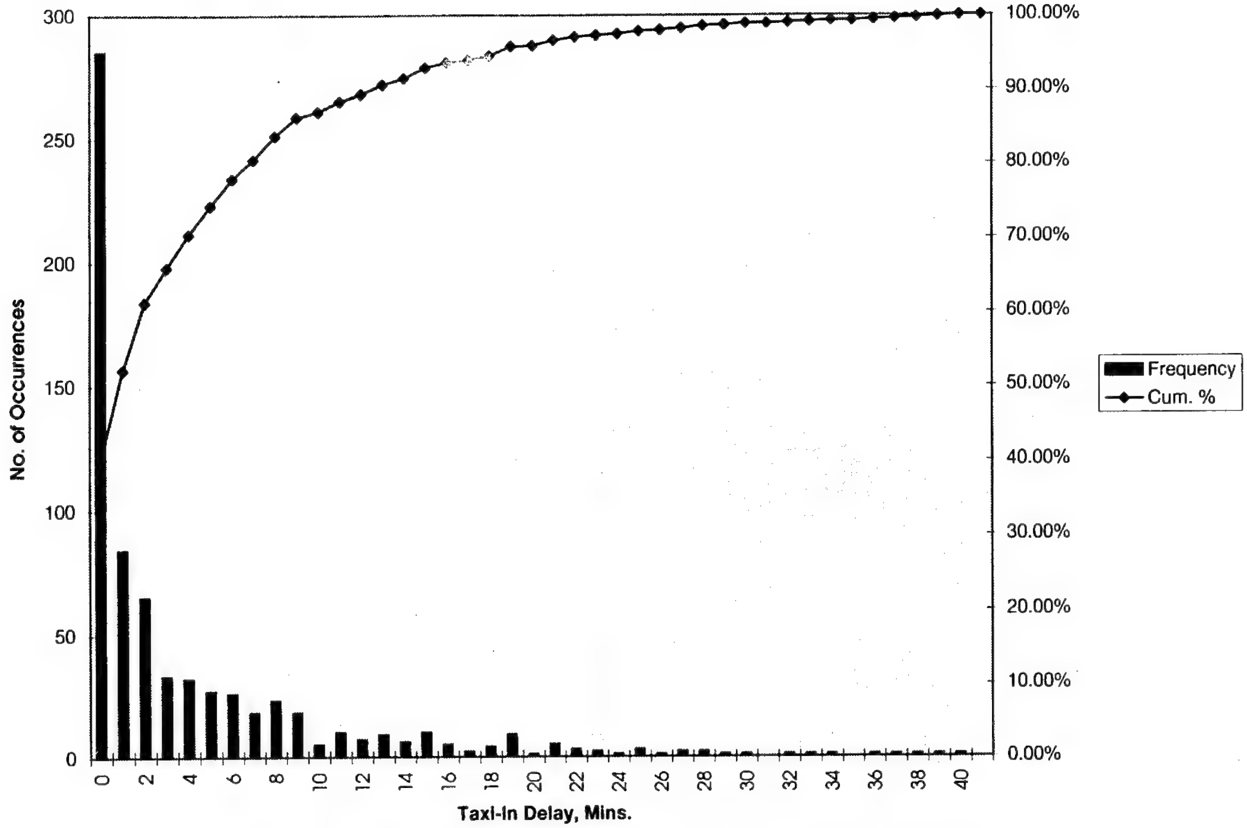


FIGURE 11. TAXI-IN DELAY, LOW IFR CONDITIONS

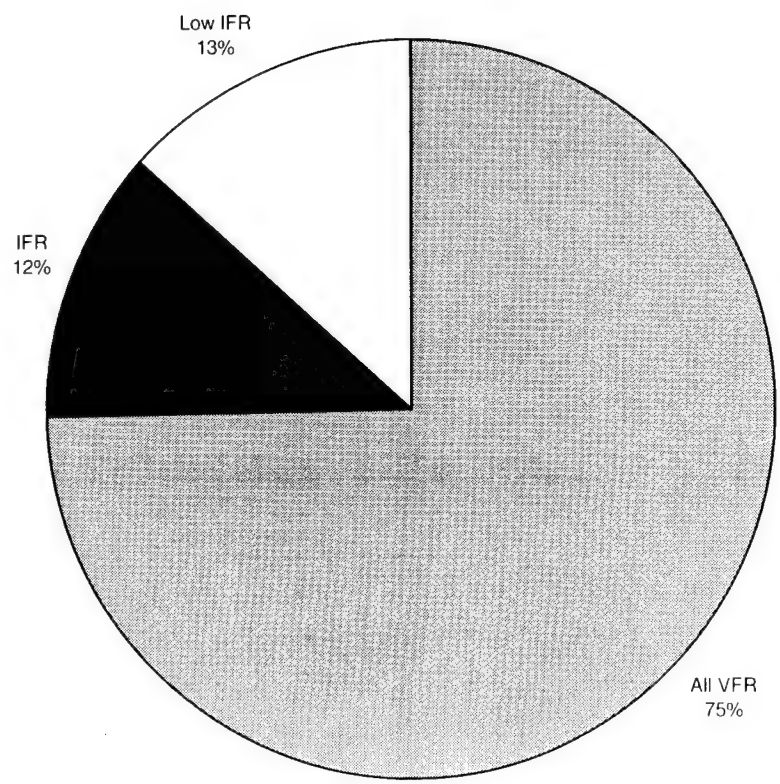


FIGURE 12. TOTAL TAXI-IN DELAY BY WEATHER CONDITION

TABLE 3. TAXI-IN DELAY STATISTICS

Weather	No. of Cases	Mean Delay (mins.)	Std. Dev. of Delay (mins.)	Aggregate Delay (mins.)
All Weather	16375	1.9	4.3	31580
All IFR	1484	3.7	6.4	5451
Low IFR	708	4.1	6.6	2887

4.2 DELAYS BY AIRPORT UTILIZATION AND WEATHER CONDITIONS USING ETMS/AIRLINE DATA

4.2.1 Departure Statistics

Figures 13 through 23 present results of the analysis as it pertains to airline departures at Philadelphia. These results are divided into four parts:

- Figures 13 through 15 show statistics on departure demand to capacity ratios
- Figures 16 through 19 show statistics on total ground departure delay by the airline, that is the sum of gate and taxi-out delays
- Figures 20 and 21 show statistics on taxi-out delays only which are parallel to those of Figures 18 and 19 for total departure delay
- Figures 22 and 23 display the relationship between departure delays and demand to capacity ratios

Figure 13 shows that for all weather conditions, 55% of the airline flights were scheduled to depart PHL during times when demand was less than capacity, and 45% of the flights during times when demand was greater than capacity. A similar relationship occurred under VFR weather conditions. Under IFR conditions, only 39% of the flights were scheduled when demand was less than capacity, and 61% when demand exceeded capacity. This shows the effect of capacity reduction under IFR conditions.

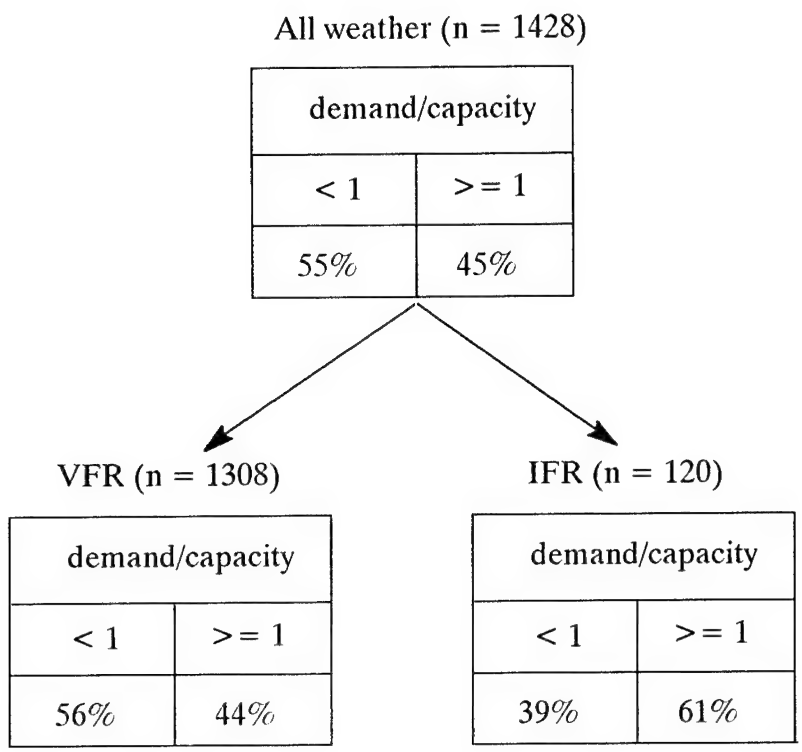


FIGURE 13. WEATHER AND DEPARTURE DEMAND-TO-CAPACITY RATIO AT PHL

Figures 14 and 15 show the distribution of airline departing flights by demand/capacity ratio under all weather and IFR conditions, respectively. Under all weather conditions, only 10% of the flights were scheduled at times when the demand/capacity ratio exceeded 1.2. The VFR distribution was very close to the all weather distribution. The corresponding percentage under IFR conditions was 34%, giving a quantitative measure of greater congestion under these conditions.

Figure 16 shows that for all weather conditions, 18% of the airline departure flights had a total ground delay greater than or equal to 15 minutes, used by the FAA as an indicator of significant delay for a flight. The VFR figure is similar. Under IFR conditions, the percentage nearly doubles to 35%.

Figure 17 shows a four-way analysis of departing flights by ground delay at PHL and by airborne and taxi-in delay at each flight's destination airport. The two types of delays do not appear to be highly correlated.

Figure 18 shows how weather affects total ground delay time. All calculations involving average delay were performed in two ways: 1) for all flights, and 2) for all flights excluding negative delays; that is, flights whose departure or arrival times were before their scheduled times. (This was not an issue in the CODAS data, where the methodology eliminates negative delays.) The average delay increased significantly between VFR and IFR conditions; for example, 10.6 to 15 minutes when excluding negative delays. Figure 19 shows these results graphically.

Figures 20 and 21 repeat the results of Figures 17 and 18 using taxi-out time only. Under all weather conditions, taxi-out delay time excluding negative delays averaged 4.1 minutes, and under IFR conditions, 6.0 minutes. These figures can be compared with the figures from Table 2 using CODAS, which had corresponding numbers of 2.8 and 3.8, respectively. The inconsistency between these results is not surprising, given the different years (1993 versus 1992) and the use of all flights versus flights from a single airline.

4.2.2 Departure Delay and Demand-to-Capacity Ratio

Figures 22 and 23 are the most significant results of the study, since they can be used directly in investment analysis. They show the relationship of average delay to the demand/capacity conditions as applied to each flight; Figure 22 uses total departure delay, and Figure 23 taxi-out delay only. As expected, average delay increases with increasing utilization of the airport, but this relationship is demonstrated quantitatively using actual airline-measured delays and actual demand-to-capacity ratios at the time of each flight.

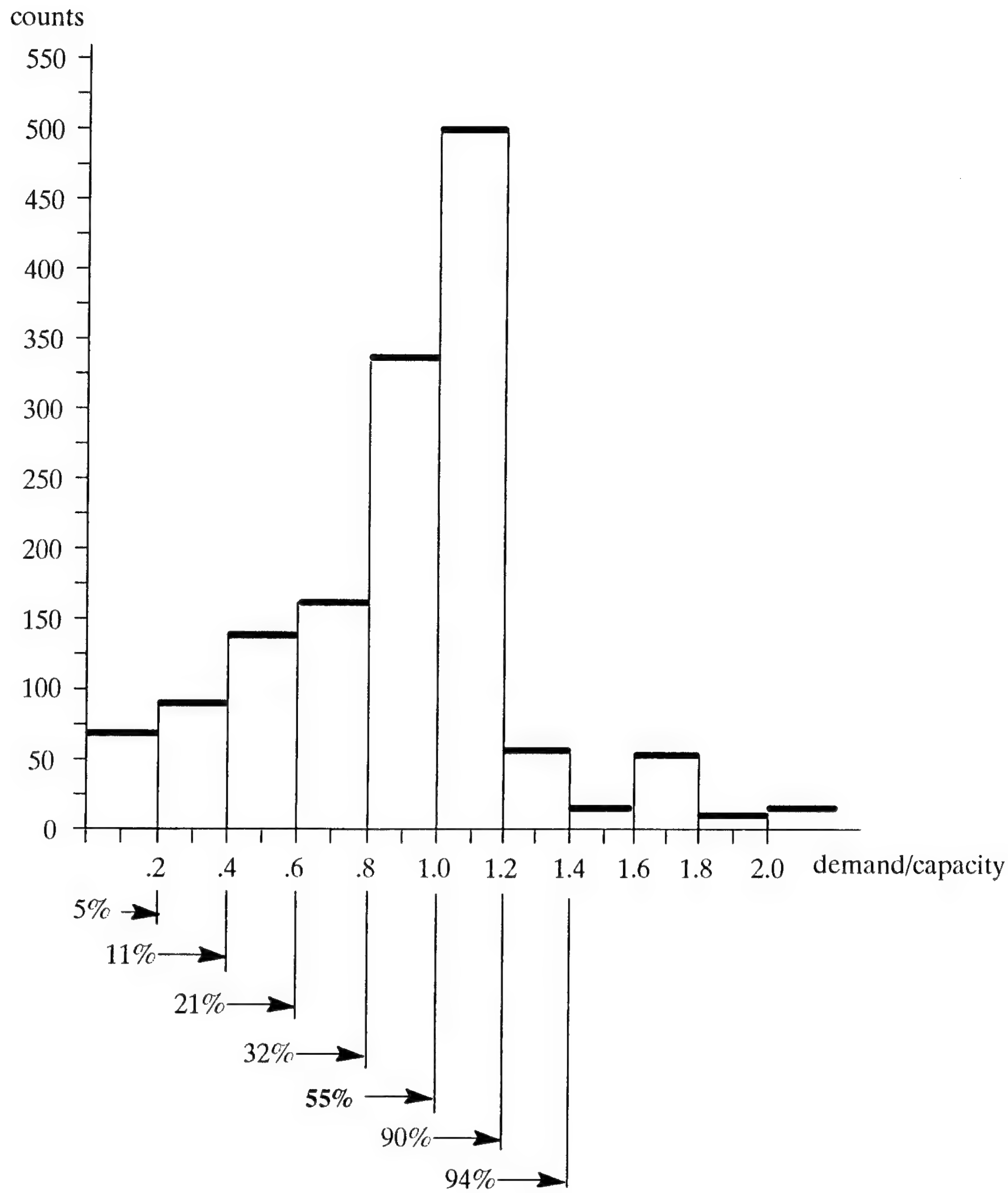


FIGURE 14. DISTRIBUTION OF DEPARTURE DEMAND-TO-CAPACITY RATIO AT PHL (ALL WEATHER)

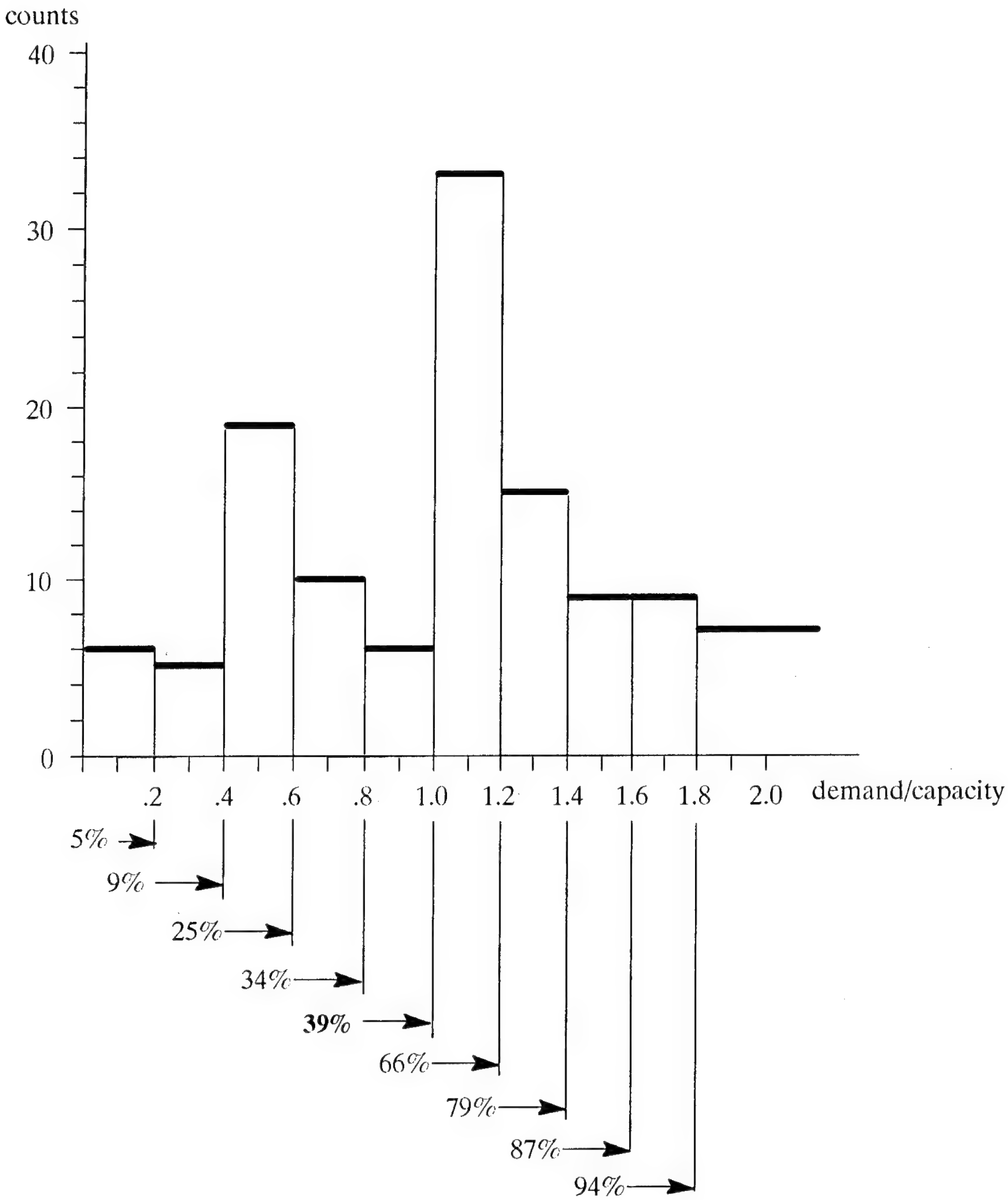


FIGURE 15. DISTRIBUTION OF DEPARTURE DEMAND-TO-CAPACITY RATIO AT PHL (IFR)

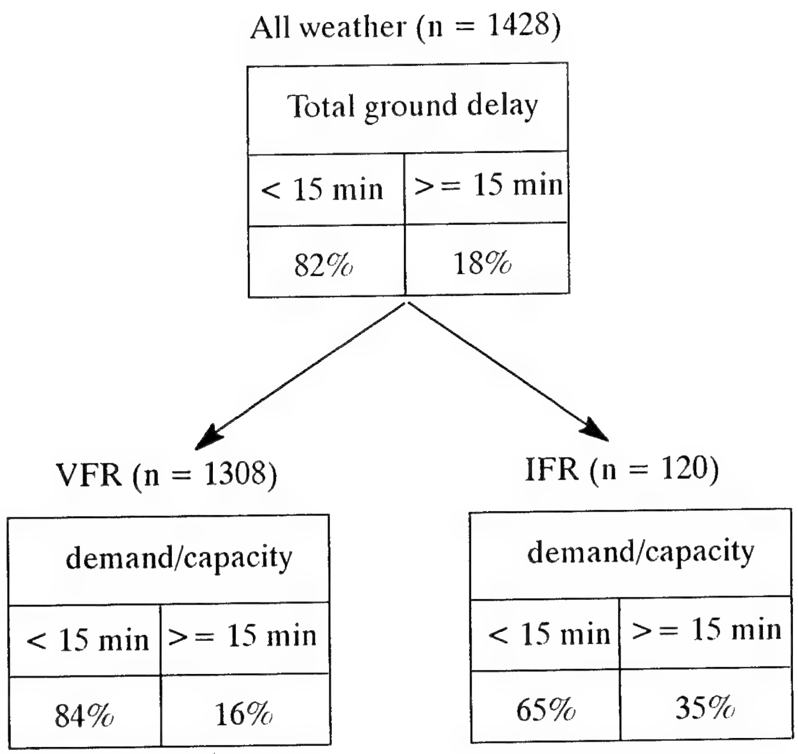


FIGURE 16. WEATHER AND TOTAL GROUND DELAY

Total ground departure delay at PHL	Total airborne and taxi-in delay at other airports	# of flights	% of flights
< 15 min	< 15 min	1083	76%
< 15 min	>= 15 min	91	6%
>= 15 min	< 15 min	226	16%
>= 15 min	>= 15 min	28	2%
TOTAL		1428	100%

FIGURE 17. DEPARTURE DELAYS AT PHL VS. TOTAL AIRBORNE AND TAXI-IN DELAYS AT THE DESTINATION AIRPORTS

All weather (n = 1428)

All flights (n=1428)		All flights excluding negative delays (n=988)	
Average delay (min)	Standard deviation (min)	Average delay (min)	Standard deviation (min)
6.6	13.9	11.1	14.6

VFR (n = 1308)

All flights (n=1308)		All flights excluding negative delays (n=879)	
Average delay (min)	Standard deviation (min)	Average delay (min)	Standard deviation (min)
6.0	13.5	10.6	14.4

IFR (n = 120)

All flights (n=120)		All flights excluding negative delays (n=109)	
Average delay (min)	Standard deviation (min)	Average delay (min)	Standard deviation (min)
13.3	16.1	15.0	16.0

FIGURE 18. TOTAL GROUND DEPARTURE DELAY TIME AT PHL

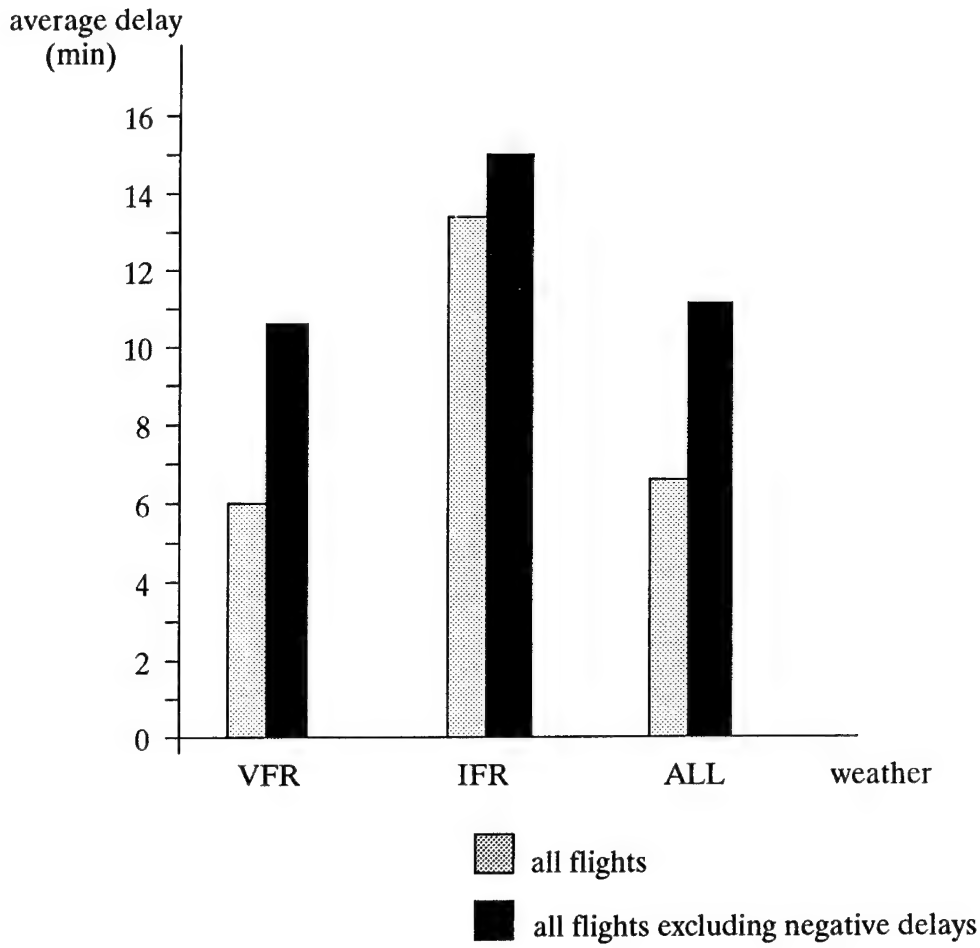


FIGURE 19. TOTAL GROUND DEPARTURE DELAY TIME AND WEATHER AT PHL

All weather (n = 1428)

All flights (n=1428)		All flights excluding negative delays (n=977)	
Average delay (min)	Standard deviation (min)	Average delay (min)	Standard deviation (min)
3.3	8.5	4.1	7.5

VFR (n = 1308)

All flights (n=1308)		All flights excluding negative delays (n=878)	
Average delay (min)	Standard deviation (min)	Average delay (min)	Standard deviation (min)
3.1	8.5	3.9	7.6

IFR (n = 120)

All flights (n=120)		All flights excluding negative delays (n=99)	
Average delay (min)	Standard deviation (min)	Average delay (min)	Standard deviation (min)
5.6	7.3	6.0	6.1

FIGURE 20. TAXI-OUT DELAY TIME AT PHL

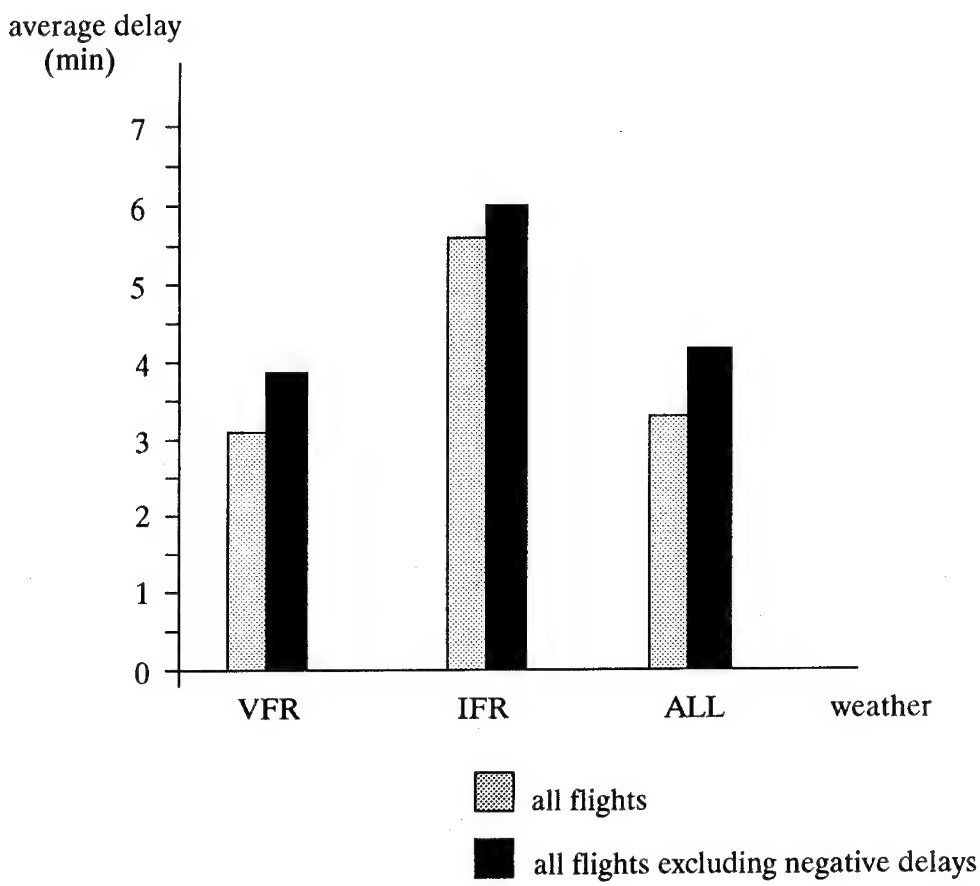


FIGURE 21. TAXI-OUT DELAY TIME AND WEATHER AT PHL

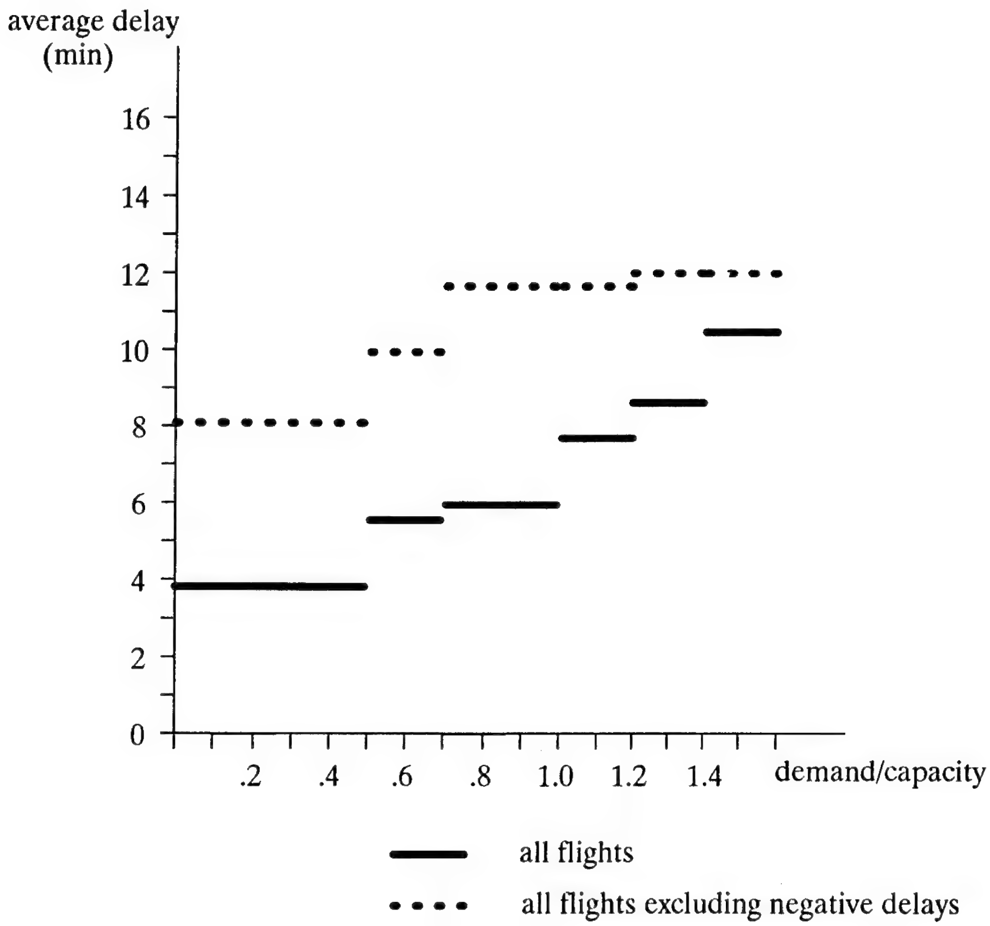


FIGURE 22. TOTAL GROUND DEPARTURE DELAY TIME AND DEMAND-TO-CAPACITY RATIO AT PHL

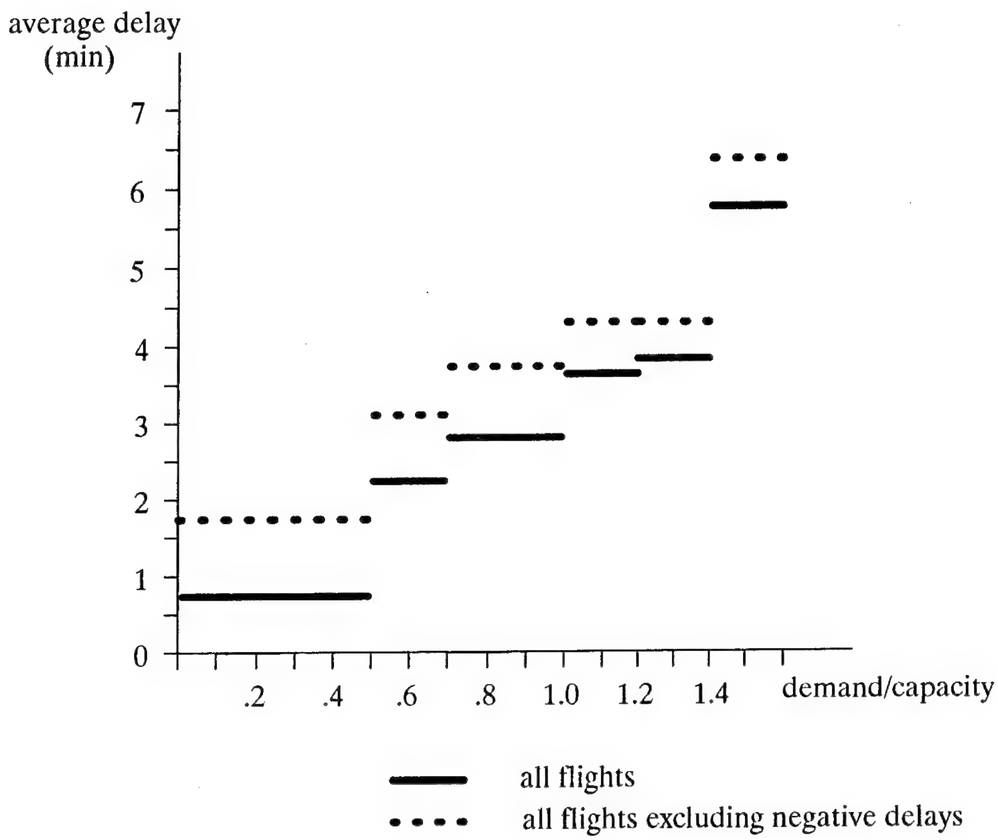


FIGURE 23. TAXI-OUT DELAY TIME AND DEMAND-TO-CAPACITY RATIO AT PHL

These results are significant for two reasons. First, the functional relationships shown in these figures can be used to estimate delay reductions which will occur from increased capacity. For example, if improved landing aids were to increase capacity under IFR conditions, the same demand profile would result in all flights occurring under these conditions to take place at a lower demand-to-capacity ratio than before, with the result that their average delay will decrease. Figures 22 and 23 can be used to calculate the magnitude of the decrease in average and therefore in aggregate delay.

Second, combining data sources for potential new analyses was demonstrated. The results of these figures were obtained by using, for the first time, accurate airline flight information with ETMS data showing the airport conditions at the time of each flight.

4.2.3 Arrival Statistics

Figures 24 through 31 present results of the analysis as pertaining to airline arrivals at Philadelphia. These results are divided in a similar manner as seen with the departure data:

- Figures 24, 25, and 26 show statistics on arrival demand to capacity ratios
- Figures 27 and 28 show statistics on total airborne and taxi-in delay by the airline
- Figure 29 shows statistics on taxi-in delays only
- Figures 30 and 31 display the relationship between arrival delays and demand to capacity ratios

Figure 24 shows that for all weather conditions, 91% of the airline flights were scheduled to arrive at PHL during times when demand was less than capacity, and 9% when demand exceeded capacity. A similar relationship occurred under VFR weather conditions. Under IFR conditions, 76% of the flights were scheduled when demand was less than capacity, and 24% under overloaded conditions. This shows the effect of capacity reductions under IFR conditions.

In contrast with departure flights, the vast majority of arrival flights were scheduled in non-overloaded conditions. Fewer flights were expected to have arrival delays. This was confirmed by further analysis as described below.

Figures 25 and 26 show the distribution of airline arriving flights by demand-to-capacity ratio under all weather and IFR conditions, respectively. These show much less of a problem of overloading than shown in Figures 14 and 15 for departing flights.

All weather (n = 1444)

demand/capacity	
< 1	>= 1
91%	9%

VFR (n = 1350)

demand/capacity	
< 1	>= 1
92%	8%

IFR (n = 94)

demand/capacity	
< 1	>= 1
76%	24%

FIGURE 24. WEATHER AND ARRIVAL DEMAND-TO-CAPACITY RATIO AT PHL

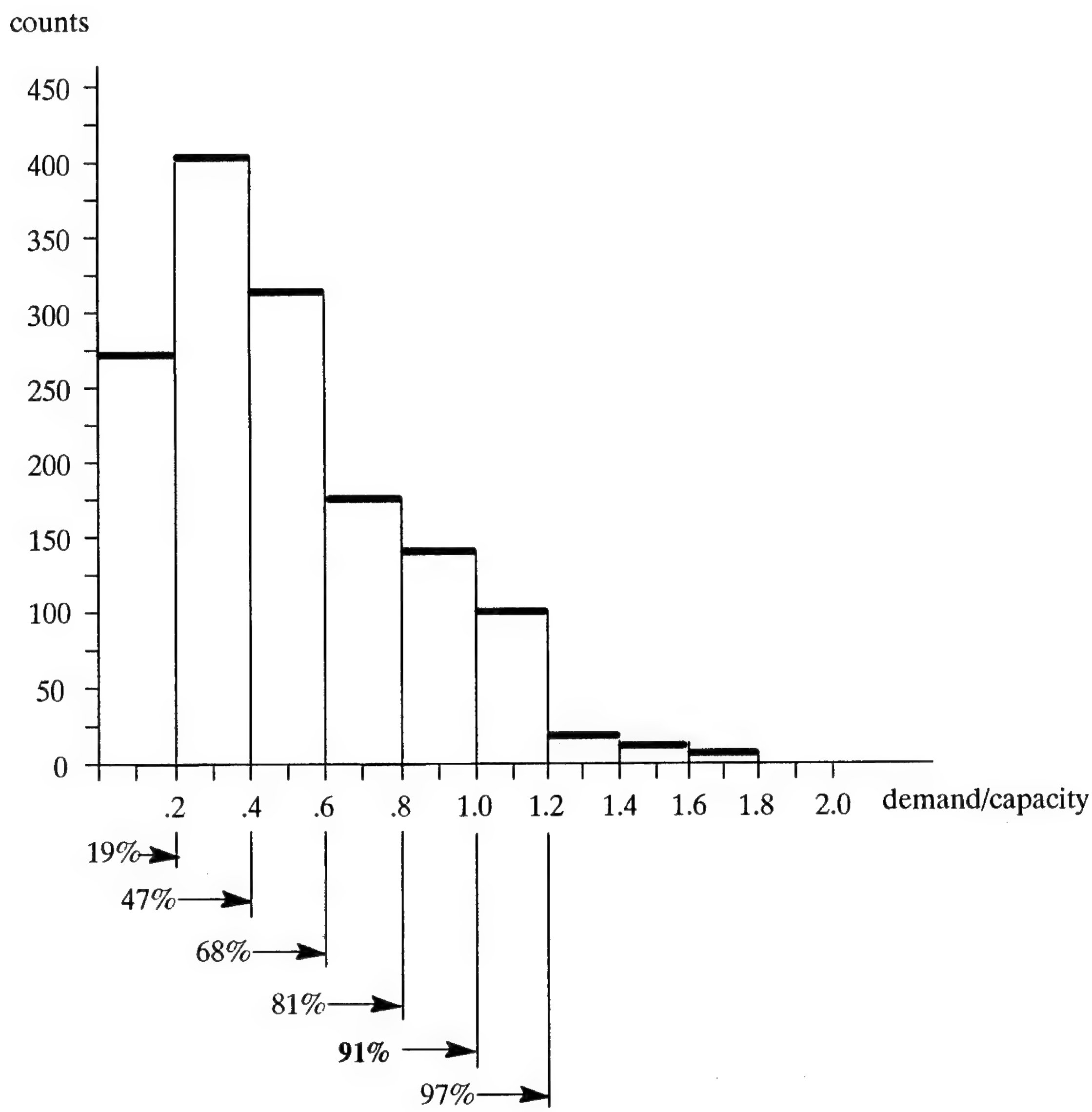


FIGURE 25. DISTRIBUTION OF ARRIVAL DEMAND-TO-CAPACITY RATIO AT PHL (ALL WEATHER)

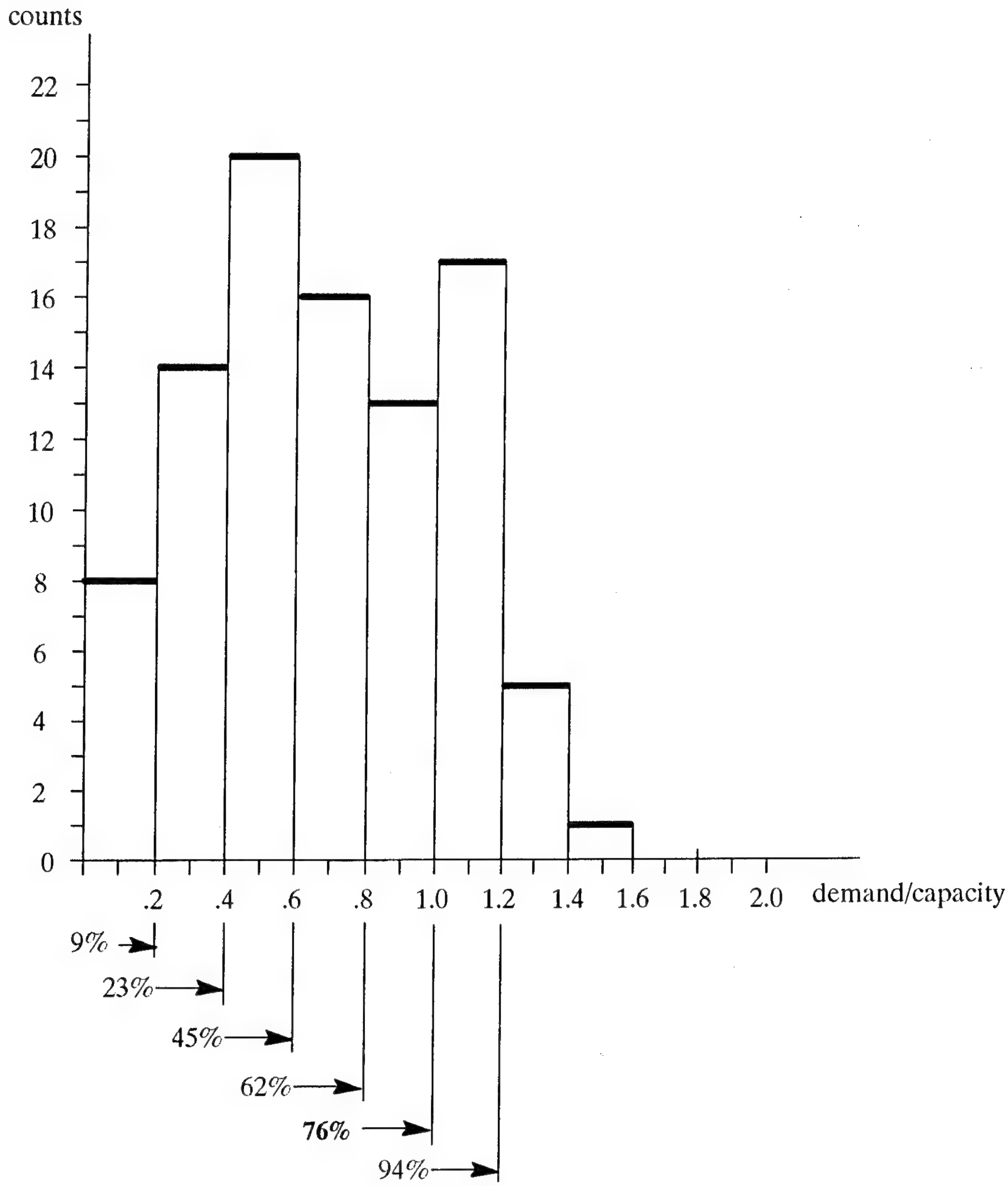


FIGURE 26. DISTRIBUTION OF ARRIVAL DEMAND-TO-CAPACITY RATIO AT PHL (IFR)

Figure 27 shows that for all weather conditions, and also for VFR conditions, only 2% of the arriving flights had a total airborne and taxi-in delay of greater than or equal to 15 minutes. For IFR conditions, the percentage increases to 10%. These relatively low percentage delays are partly due to the fact that airline delays after departure can only be measured against a planned schedule, which is stretched out for marketing reasons. This is borne out by Figure 28, showing negative average delays (i.e., early arrivals) when all flights are considered. This means that a great many flights beat the schedule for arrival. The data show that even when negative delays are excluded, the average delays are rather small.

Figure 29 shows that under all weather conditions, taxi-in delay excluding negative delays averaged 0.9 minutes, and under IFR conditions, 1.3 minutes. These figures can be compared with the figures from Table 3 using CODAS, which had corresponding numbers of 1.9 and 3.7, respectively. Although both data sets showed higher taxi-out delays than taxi-in delays, the difference between the two was greater in the airline data than in the CODAS data.

4.2.4 Arrival Delay and Demand-to-Capacity Ratio

Figures 30 and 31 show the relationship of average arrival delays to demand/capacity conditions in a similar manner as Figures 22 and 23. As stated earlier, these figures can be used to estimate, quantitatively, the benefit from increased airport capacity. As expected, average arrival delay increases with demand/capacity ratio, but in a less marked and consistent manner than shown with departure delay.

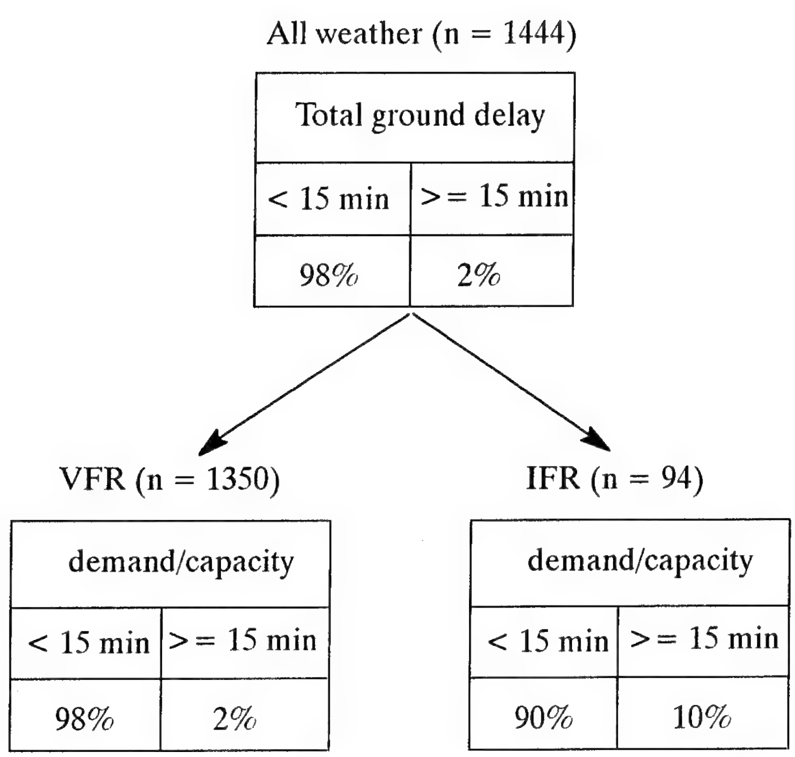


FIGURE 27. WEATHER AND TOTAL AIRBORNE AND TAXI-IN DELAY FOR ARRIVAL FLIGHTS AT PHL

All weather (n = 1444)

All flights (n=1444)		All flights excluding negative delays (n=334)	
Average delay (min)	Standard deviation (min)	Average delay (min)	Standard deviation (min)
−5.7	8.0	1.7	4.2

VFR (n = 1350)

All flights (n=1350)		All flights excluding negative delays (n=290)	
Average delay (min)	Standard deviation (min)	Average delay (min)	Standard deviation (min)
−6.0	8.1	1.5	3.6

IFR (n = 94)

All flights (n=94)		All flights excluding negative delays (n=44)	
Average delay (min)	Standard deviation (min)	Average delay (min)	Standard deviation (min)
−2.7	12.3	4.9	8.9

FIGURE 28. TOTAL AIRBORNE AND TAXI-IN DELAY TIME AND WEATHER AT PHL

All weather (n = 1444)

All flights (n=1444)		All flights excluding negative delays (n=979)	
Average delay (min)	Standard deviation (min)	Average delay (min)	Standard deviation (min)
0.5	1.8	0.9	1.3

VFR (n = 1350)

All flights (n=1350)		All flights excluding negative delays (n=895)	
Average delay (min)	Standard deviation (min)	Average delay (min)	Standard deviation (min)
0.5	1.8	0.9	1.4

IFR (n = 94)

All flights (n=94)		All flights excluding negative delays (n=84)	
Average delay (min)	Standard deviation (min)	Average delay (min)	Standard deviation (min)
1.1	1.5	1.3	1.1

FIGURE 29. TAXI-IN DELAY TIME AT PHL

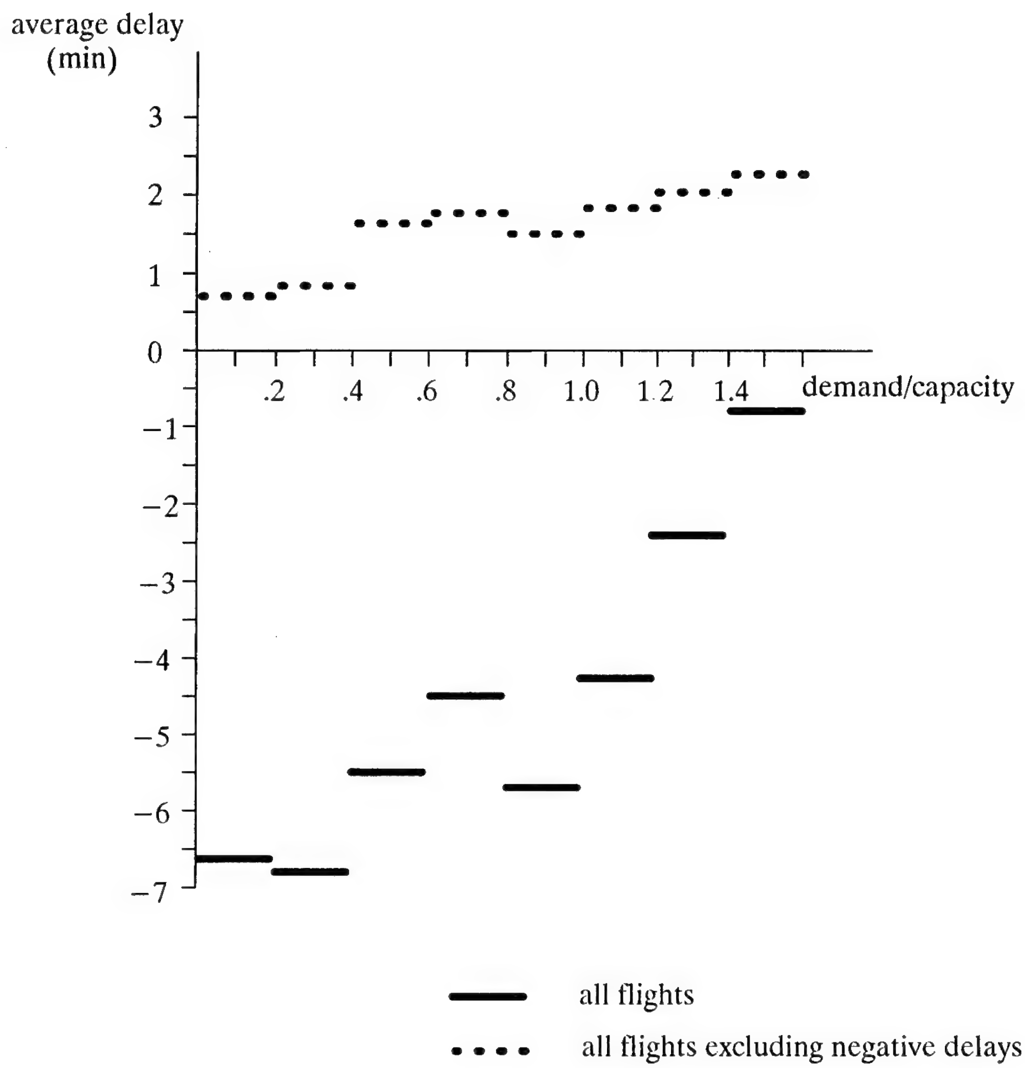


FIGURE 30. TOTAL AIRBORNE AND TAXI-IN DELAY TIME AND DEMAND-TO-CAPACITY RATIO AT PHL

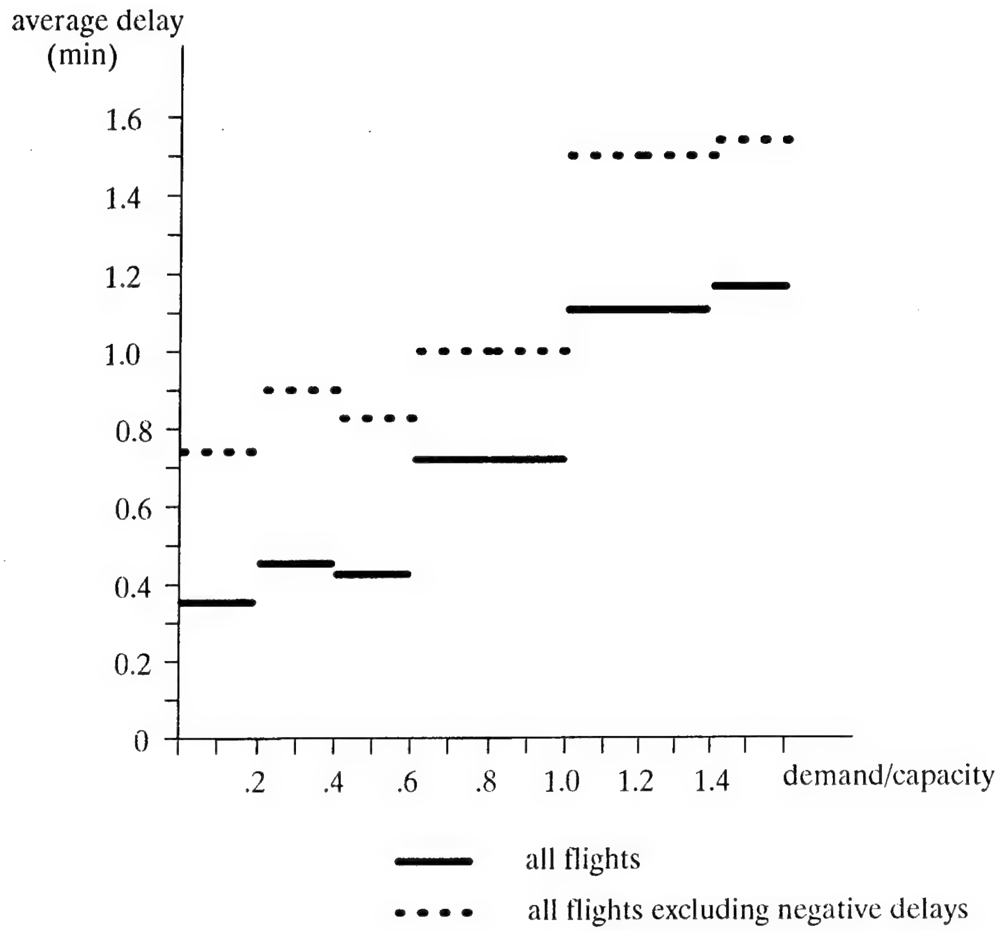


FIGURE 31. TAXI-IN DELAY TIME AND DEMAND-TO-CAPACITY RATIO AT PHL

5. LIMITATIONS

The primary benefit of this pilot study was to demonstrate a viable methodology for addressing issues of airport performance. The results presented above cannot be used in subsequent analyses or decisions because of many limitations, some of which are described below.

1. Both data sets used covered a few months of a year. The data differed greatly from one month to the next due to weather conditions. At a minimum, any data analysis should cover a whole year to include all normal weather variations.

2. Due to time and resource limitations, the following available data were not used:

   - gate departure information available in CODAS
   - EDCT information available in both data sets
   - gate delay reasons available in the airline data

3. Flights which do not have flight plans do not get captured in the ETMS data base. Such flights are general aviation flying under VFR weather conditions. For PHL, about 12% of operations are general aviation,[9] however this will include many corporate jets and other aircraft choosing to file flight plans, and aircraft required to file flight plans due to IFR weather conditions. Therefore the analysis for PHL will not be significantly affected.

   However, for other high-operation airports like Santa Ana/John Wayne in California at which over 70% of non-local operations are general aviation, the methodology used in this report will be inadequate.

4. The OOOI data were only available on a single airline; the different airlines using Philadelphia have very different schedule and flight length statistics. For example, the differences between the results of Figures 14 and 15 and the results of Figures 25 and 26, showing fewer arrival flights scheduled during high demand conditions, may be a function of that particular airline and its schedule. Without more comprehensive airline data, one can only speculate what is happening here.

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[9] Federal Aviation Administration, FAA Air Traffic Activity for Fiscal Year 1993, Table 3-1.

5. The study could not use airport configuration as a variable, since the data of exactly when each configuration was in effect was not available at Philadelphia. The accuracy of capacity curves such as shown in Figure 4 would be much improved if they were keyed to specific configurations. The methodology of the study may have to be modified to utilize airport configuration and weather as independent data sets.

6. POTENTIAL APPLICATION TO INVESTMENT DECISIONS

By showing under what conditions most delays occur at a given airport, investments whose primary goal is efficiency payoffs can be tailored to that problem. For example, if most delays occur because bad weather limits effective capacity, investments in landing aids would be most appropriate. If most delays occur because demand is saturating the airport under good weather conditions, airport expansion would have to be considered, along with the alternative of diverting traffic to other airports in the metropolitan area.

In conducting an analysis of this kind, developing charts similar to those in Figures 22-23 and Figures 30-31 will be highly valuable. These charts show a quantitative relationship between average delay and the demand/capacity ratio. This relationship would allow an easy estimation of the average delay reduction, and the total delay reduction, which would result from increasing airport capacity under either VFR or IFR conditions. This is a missing link between calculations of increased capacity due to airport investments of various kinds, and the aggregate benefits to be derived from these investments.

7. CONCLUSIONS

This study has demonstrated a methodology for integrating aviation databases to address a practical problem, namely measuring airport performance. Statistical analyses of this issue have been conducted on two separate databases. Departure and arrival delays were analyzed relative to weather conditions, and in relation to both weather and airport utilization.

In particular, for the first time, OOOI data from an airline have been combined with ETMS data, linked by time of flight. Therefore, accurate airline data could be used in conjunction with airport conditions at flight time. A quantitative relationship was found between average delay and the demand/capacity ratio at the airport, which should prove after more extensive studies to be useful in the investment analyses of airport improvements. If the FAA is successful in negotiating large-scale use of OOOI data from the major airlines, extensions of the methodology shown here should help create accurate metrics to aid in investment decisions.